Faculty of Science and Engineering
School of Applied Geology

Palynology of the Narnoo palaeovalley, Western Australia, and its implications for the biostratigraphy and palaeovegetation of southern Australia

Charlotte Lesley Mack

This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University

March 2016

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature: 

Date: 15/11/2016

Abstract

Well-preserved and diverse late Eocene palynofloras have been recovered from the Mulga Rock uranium exploration site currently operated by Vimy Resources, in a palaeovalley incised into the southern Officer Basin of Western Australia (WA). Study of WA Paleogene palynofloras has been impeded by the limited vertical and lateral extent of sedimentary units of this age in southern WA, and until recently, minimal associated mineral exploration and funding for research. In contrast, numerous studies of thick sediment sequences in the Gippsland, Otway and Murray basins, have been used to construct detailed palynostratigraphic zonation schemes. Age dating in WA using these schemes has been problematic and inconsistent, with key index species occurring outside of the age ranges defined for the Gippsland and Murray Basin palynozonations, and updates to the zonation schemes not being consistently applied. The southeastern Australian studies have also interpreted the mid-late Eocene palaeovegetation as a mesothermal *Nothofagus*-dominated rainforest, an interpretation often extended to the palynofloras of Western Australia. The regional variation of the mid-late Eocene palaeovegetation recognised in WA, and the presence of sclerophyllous and xeromorphic indicators in both the spore-pollen and macrofossil records, is difficult to reconcile with a mesothermal *Nothofagus*-dominated rainforest.

The current lithostratigraphy for Mulga Rock is informal, and the defined sedimentary units require dating and palynostratigraphic characterisation. A cross section of eight drill holes through Vimy's Ambassador and Princess uranium deposits was studied. A total of 72 sediment samples from lignitic, clay and carbonaceous sand intervals were selected, of which 58 samples were productive. The palynofloras contain 163 previously described pollen and spore species and 36 new species. Eighteen new species are formally described; *Banksieaeidites cooksonii, B. davidsonii, Myrtaceidites corymbioides, Proteacidites ambassadatus, P. colubrimodus, P. crochetaria, P. microspinosus, P. narnooensis, P. polygonalis, P. protrudens, P. rickmanii, P. tesselaria, P. vaga, Rhoipites oralongii, R. orbiculatus, Tricolpites discoides, T. occultum* and *T. reticularis*. The Mulga Rock palynoflora is dated as late Eocene (Middle *Nothofagidites asperus* Zone equivalent

of the Murray Basin) based on the presence of *Algaoreidia qualumis, Anacolosidites sectus, Proteacidites confragosus, P. tuberculatus, Rhoipites sphaerica, Santalumidites cainozoicus, Sapotaceoidaepollenites rotundus, Tricolpites incisus* and *T. thomasii.* Morphological comparison of the two new species of *Banksieaeidites* spp. with pollen of eight extant *Banksia* confirms (i) the alignment of these species with the genus, and (ii) that they are distinct from the Musgraveinae affiliate *B. arcuatus.*

Trends in the percent occurrence of major plant groups and species related to lithostratigraphic boundaries include an increase in *Haloragacidites harrisii* in clay-rich units, high *Proteacidites* within sandier intervals and the restriction of individual species to lithostratigraphic sub-unit and units. The boundary between the mostly sand-rich with minor clay sub-units of Vimy's Unit D, and the lignitic to carbonaceous sands of Unit E, is distinguished by the distribution of individual pollen species; the last appearance of *Proteacidites ivanhoensis, P.* cf. *P. pseudomoides* sp. 1, *P, microverrucatus, P. leightonii, P. colubrimodus* and *P. kopiensis*. The start of Unit E is also marked by the first appearance of *Anacolosidites luteoides, Arecipites waitakiensis, Parvisaccites catastus, Proteacidites punctiporus, P. tesselaria, Rhoipites aralioides* and *Triporopollenites delicatus*. Sub-unit D2 is potentially characterised by high *Proteacidites* spp. *Haloragacidites harrisii* is lower in E1, increasing into the E2 sub-unit. Two pollen species are also restricted to the E2 interval: *Podocarpidites puteus* and *Proteacidites crochetaria*.

The sedimentology suggests a meandering river system within a palaeovalley, with associated point bar, flood plain and swamp environments. Species such as *Haloragacidites harrisii* and *Banksieaeidites* spp. show a relationship with the swampier environments and high values of *Proteacidites* spp. are associated with sandier intervals. Both *Banksia* and *Proteaceae* use animal/insect pollen vectors today and were likely occurring in the local vegetation. *Proteacidites* spp. in particular may have been adapted to low soil fertility, like many extant *Proteaceae*. It is harder to identify the distribution of *H. harrisii* as many Casuarinaceae distribute pollen via wind vectors.

Dominance varies between *Haloragacidites harrisii, Nothofagidites* spp. and *Myrtaceidites* spp. across all samples and these changes in percent occurrence are suggestive of differences in environment and palaeovegetation communities at the site. The *Myrtaceidites* spp.-dominated assemblages include a diverse proteaceous component. *Proteacidites carobelindiae, P. cirritulis* and *P. punctiporus* have previously been aligned with extant Conospermeae and, in combination with high numbers of myrtaceous species, indicate a more sclerophyllous nature to the vegetation than that of southeastern Australia in the Eocene. *Myrtaceidites* spp. also show a preference for drier environments at other sites in southern Australia. The two new *Banksieaeidites* spp. described, occurring up to 7% in assemblages, also indicate a sclerophyllous community was present. Many of the *Banksia* macrofossils dated as late Eocene show evidence of sclerophylly, and one xeromorphy. These assemblages suggest that more of the late Eocene vegetation of WA may have been woodland, dry forest and/or heath than previously thought.

This study provides palynological trends associated with lithostratigraphic boundaries that can be used to formalise the palynostratigraphy of the Mulga Rock site in the future. The comprehensive assessment of the palaeovegetation and depositional environments represented by the Mulga Rock palynofloras also furthers the study of palynology in WA, in particular the understanding of the regional variation present compared to the *Nothofagus*-dominated mesothermal forests of southeastern Australia.

Acknowledgements

'The most important things are the hardest things to say. They are the things you get ashamed of because words diminish your feelings – words shrink things that seem timeless when they are in your head to no more than living size when they are brought out' – **Stephen King**

First and foremost, my supervisors have my deepest gratitude. Dr Aaron Hunter took on a lot in the last few months of the project and contributed a lot to getting the work up to scratch. Dr Milo Barham is thanked for finding where figures were lacking and his practical advice and support throughout the project. Associate Professor Kate Trinajstic's experience was invaluable in setting up the early stages of the project. I'm grateful to her facilitating much of the logistics and paperwork that organises a PhD student, teaching me the order in which to construct a paper and her encouragement to attend conferences – an experience that was way out of my comfort zone but incredibly rewarding thanks to her guidance. Last but not least, my main supervisor Dr Lynne Milne, who I can probably never say enough about. She brought a wealth of knowledge that she was so glad to impart, as well as an infectious love of Eocene palynology and Proteaceae. I have her to thank for so much of this as she has been a driving and supportive force behind this project. Thank you for taking the late night phone calls, keeping me on task and being a friend/second mother all at once.

I'm also grateful to the people who provided material for the project, including samples, figures and information. Energy and Minerals Australia (EMA, now Vimy Resources) are thanked for taking an interest in the project and providing the samples, funding and information integral to this work. In particular; Xavier Moreau for organising much of the logistics of site and material access and his ongoing interest in the work; Andrew Dowley who facilitated everything on site at Mulga Rock, from plotting cross sections to sample, access to sample storage and imparting much of what I know about the geology of the site; Lorraine Picolet who drafted figures, found drill logs and was my tour guide on site. Mike Fewster is thanked for providing much of the background on everything geological at Mulga Rock and his

encouraging support of the project while with EMA. The Perth Herbarium granted permission to collect modern *Banksia* pollen from specimen sheets. I would like to acknowledge the use of equipment, scientific and technical assistance of the Curtin University Electron Microscope Facility, which has been partially funded by the University, State and Commonwealth Governments. Thanks to Elaine Miller at this facility for taking the time to train me and for the amazing SEM photographs that resulted. I am grateful to Dr Ray Carpenter for his encouragement and sharing his knowledge of *Banksia*. I'm also thankful to Dr Sarah Martin of the Geological Survey of Western Australia – thank you for taking my samples and slides in, lending me an England Finder and most of all for the chats and advice. Thanks goes to Associate Professor Ron Watkins and the Environmental Inorganic Geochemistry Group for providing me with lab space and equipment and to the Fuels and Energy Technology Institute, and their fantastic lab manager Angelina Rossiter, for the same when EIGG moved.

Sincere thanks goes to the friends that supported me through this. Luke Daly, who understands that coffee and donuts can solve most PhD dramas. Dr Jason Hamer, for being the one who got through all this first, patiently listened to my crises, and shared support and advice. Brett Ashworth for being a friend through it all, Honours and PhD, and knowing exactly what I was going through and supporting me through it. For the wonderful Curtin Applied Geology PhD cohort I am so thankful, you have all been there for me at some point and will be there to celebrate with me when everything is done. This includes you, Rob Howie; we've definitely adopted you as a geologist. Most importantly, thank you Steffan Thomson, for being so wonderfully patient, thoughtful and supportive. You've really been my rock the past few years.

Lastly, I owe everything to the people that are the hardest to say a few words about, my amazing family. Big thanks to my step dad, Kelvin Murphy, who is probably solely responsible for me eating anything healthy while I finished writing this and always has wise words of advice for me. Thank you to my step mum, Jullie Forward, you've always imparted a lot more positivity into my life. Thanks to my aunties, your interest and encouragement mean more than you know. I have a lot of gratitude for my wonderful grandmother, who has always encouraged the scientist in me, no matter what age. To my grandad, for always understanding why I had to do this, and

reading everything I've written so far. Leaving the best for last, I am so grateful to have two parents that are thrilled with everything I achieve. To my dad, I think it may surprise you, but many of the research skills I've needed to finish this I started learning from you. Thank you for always encouraging me to learn more. Loving thanks to my mum, who has always kept me grounded but still goes above and beyond to encourage me. You've always been my go to for puzzling out the big decisions in life and I can't ever say enough. I hope you both know I could have filled a page!

Support from an Australian Postgraduate Award and a Curtin University Postgraduate Scholarship are gratefully acknowledged. The receipt of a travel grant from the American Association of Stratigraphic Palynologists was greatly appreciated.

Table of contents

List of figures

List of tables

1. Introduction

Palynology is a valuable geological tool, with applications in biostratigraphy and the reconstruction of palaeovegetation, environments of deposition and climatic variability. The correlation of pollen and spore assemblages, and changes in percent occurrences of genera and individual species with depth, are also important for understanding lithostratigraphic and facies relationships in exploration for oil and gas, minerals and groundwater.

The Paleogene of southeastern Australia is palynologically well-studied, and thick intervals of sediment in the southeastern Otway (Harris 1971), Gippsland (Stover and Partridge 1973, Partridge 1976, Partridge 2006) and Murray Basins (Macphail 1999) have allowed for the construction of standard palynostratigraphic schemes. These schemes have been extrapolated Australia-wide to date sediments of Cretaceous to Cenozoic age. The development of a Cenozoic palynostratigraphic scheme for southern WA has not been possible, as the units of similar age are of limited vertical and lateral extent, with no sections spanning more than one standard palynological zone established in the eastern states. Widespread, but limited, Paleogene studies have been completed in Western Australia (WA) (e.g. Bremer Basin, Stover and Partridge 1982; Zanthus, Milne 1988; palaeodrainages, Balme and Churchill 1959) but rely on extrapolation of the southeastern Australian palynozones. Problems arise when using these zones to date WA palynofloras, as many new species occur in the west, some of which are described, but many are not. Diachronism in the age ranges of many of the index species for southeastern Australian basins is also apparent in WA. Milne (1988) noted species with age ranges spanning four Gippsland Basin zones in the same palynoflora at Zanthus, in the western Eucla Basin. Partridge (1976) divided the Lower *Nothofagidites asperus* Zone of Stover and Partridge (1973), formally erecting the Middle *Nothofagidites asperus* Zone, an amendment that has not often been followed in WA. Numerous unpublished company reports have used only the zones erected by Stover and Partridge (1973) (e.g. Islam 1983, Parker 1988) with stratigraphic compilations carrying through these inconsistencies (Clarke *et al.* 2003).

The *Nothofagus*-dominated mesothermal rainforest interpreted for the southeastern Australian basins during the middle to late Eocene has been assumed to have extended throughout southern Australia (Hos 1975, Stover and Partridge 1982, Macphail *et al*. 1994). Despite (i) provincialism in the WA Eocene palynofloras being recognised by Hos (1975) and Milne (1988), (ii) the presence of pollen assemblages indicative of a sclerophyllous plant community (Milne 1988, 1998; Mack and Milne 2015), and (iii) evidence of xeromorphy in the macrofossil record (Carpenter *et al.* 2014); the interpretation of a mesothermal *Nothofagus* rainforest extending across southern Australia at that time still persists (e.g. Macphail 2007).

Published palynological studies on Paleogene sediments in the southern Officer Basin are limited to a publication on the sediments contained within what is informally known as the 'Narnoo palaeovalley', which is presented as a part of this thesis (Mack and Milne 2015). The ongoing exploration work of Vimy Resources Ltd., the current tenement owners of Mulga Rock, has relied on the use of a preliminary stratigraphic scheme (Fewster 1999, Vimy Resources pers. comm.). Palynology can be used to constrain the informal lithostratigraphic units comprising this stratigraphy and provide an age, environment of deposition, and assessment of the palaeovegetation.

This study aims to characterise and date the palynoassemblages present in the Narnoo palaeovalley sediments in order to:

- Constrain the informal lithostratigraphic units in use by Vimy and their environments of deposition
- Analyse changes in palynoassemblages and the relationships of these to lithostratigraphic units and environments of deposition
- Understand the implications of the assemblages present for the Eocene palaeovegetation of southern WA, its relationship to that of southeastern Australia and its significance for the development of the modern sclerophyllous/xeromorphic flora in southern Australia.

To achieve this, a cross-section through seven drill holes was plotted across the Ambassador uranium ore deposit at Mulga Rock, with an additional drill hole in the Princess deposit, to characterise the pollen assemblages and changes with depth across a significant interval of carbonaceous sediments.

This thesis is organised as follows; chapter 2 constrains the distribution of sediments of Paleogene age in southern Western Australia and describes the study area. Chapter 3 outlines the previous palynological and palaeobotanical work that has been completed in southern Australia on assemblages of Paleogene age. Chapter 4 describes the materials available, and the methods used in this research project. Chapter 5 outlines the fossil pollen and spore species present in the Mulga Rock assemblages that have been described in previous work. Chapter 6 contains the formal systematic description of 16 new species, and brief notes on a further 20. Chapter 7 discusses the distribution of major spore-pollen groups in the Mulga Rock assemblages, as well as the distribution of individual species. This chapter aims to categorise those trends that may have implications for the delineation of stratigraphic boundaries and depositional environments at Mulga Rock. Chapter 8 gives an age for the Mulga Rock assemblages, discusses the palaeoenvironments and palaeovegetation indicated and compares this to other southern Australian palynological studies. This chapter includes the paper Mack and Milne (2015), published in Alcheringa. Chapter 9 describes two new species of *Banksieaeidites* spp., the affinity of which is confirmed by morphological comparison with pollen produced by extant *Banksia* L. f. This chapter also discusses the implications of these new species for the palaeovegetation of the study site and southern Western Australia and has been accepted for publication in Australian Systematic Botany. Chapter 10 draws conclusions from the discussion chapters 7, 8 and 9.

2. Geological setting

2.1 Regional: Paleogene sediments of southern Western Australia

Sediments of Paleogene age in southern Western Australia (WA) are known from the Eucla and Bremer basins, as well as the Perth Basin (Fig. 2.1, Table 2.1). The most current basin terminology for the southern margin of Western Australia groups the onshore Cenozoic units of the Bremer into the Eucla Basin (Bradshaw *et al.* 2003). As many pre-2003 palynological studies refer to the Bremer Basin it is still noted as a separate location herein, though the stratigraphy outlined by Clarke *et al.* (2003) is used for both the Eucla and the Bremer. Similar aged intervals also occur in palaeodrainage systems on the Yilgarn Craton and on the margins of the Eucla Basin (Fig 2.2, Table 2.1).

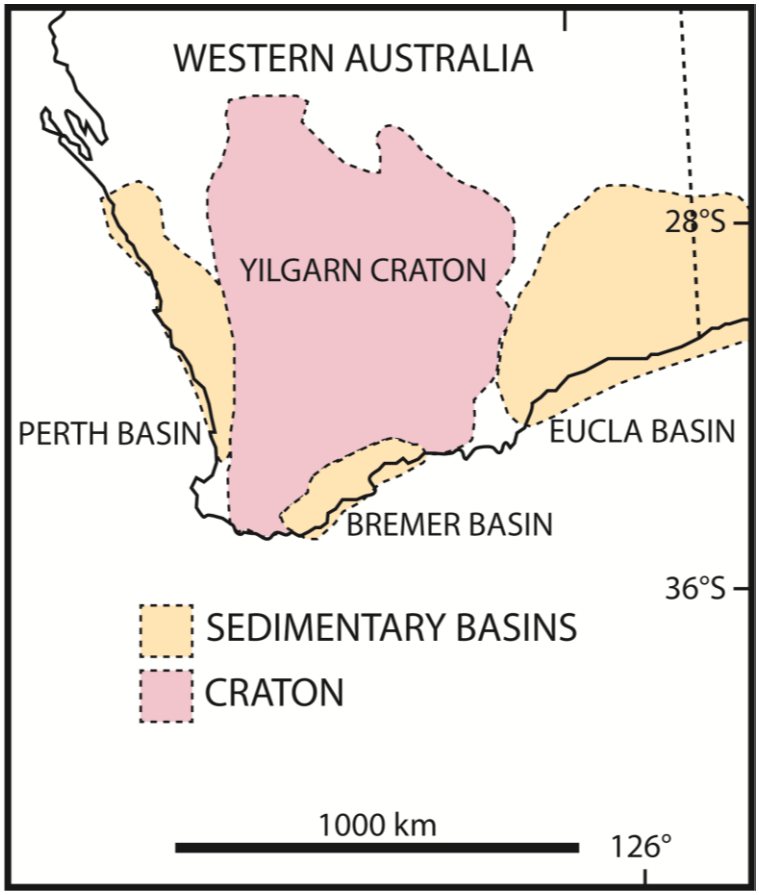


Fig. 2.1 Location of sedimentary basins and the Yilgarn Craton in southern Western Australia.

An understanding of the lithostratigraphy applied to Paleogene sediments in southern WA also requires knowledge of the associated biostratigraphy. Relative ages for many of the sedimentary intervals are derived from palynostratigraphy, the standard zonation schemes of which have been amended (as described in Chapter 3) since the publication of many sedimentological studies of these sites. These amendments to the standard zonation scheme are not always recognised in the literature outlining the Cenozoic stratigraphy of Western Australia. Many studies (Clarke *et al.* 2003, Hou *et al.* 2006, 2008) align their lithostratigraphic nomenclature with the zones of Stover and Partridge (1973), and do not recognise the further refinement of the zones by Partridge (1976). This means that some reported Lower *N. asperus* zone assemblages may actually be Middle *N. asperus* assemblages, and therefore the former is reported as middle Eocene in age instead of late Eocene.

Table 2.1 Lithostratigraphic formations of Paleogene age in southern Western Australia as referred to in this review.

	BASINS		**PALAEODRAINAGES**					
	Eucla	**Perth**	**Beaufort**	**Cowan**	**Roe**	**Lefroy**	**Zanthus**	**Muir-Unicup**
late Eocene	Werillup	-	Unnamed Unit	Werillup	Werillup	Werillup	Werillup	Werillup
middle Eocene	North Royal	-	-	North Royal	North Royal	-	-	-
Palaeocene	-	Kings Park	-	-	-	-	-	-

2.2 Basins

2.2.1 Eucla/Bremer

The Eucla Basin was formed during the late Cretaceous to middle Eocene separation of Australia and Antarctica (Veevers 2000, Li *et al.* 2003), and infilled dominantly by carbonate platform sedimentation. The western onshore margin has been influenced by input from an extensive palaeodrainage system and is dominated by clastic terrigenous sediments.

The stratigraphic nomenclature of the Eocene sedimentary succession in the Eucla Basin and along its margins has had a complicated history (McWhae *et al*. 1958, Lowry 1968, 1970, Playford *et al.* 1975). However, the revision of the Eocene stratigraphic nomenclature for southern WA by Clarke *et al.* (2003) greatly simplified it and also extended the Eucla Basin lithostratigraphic divisions to cover the onshore sediments of the Bremer Basin. Clarke *et al*. (2003) recognised two non-marine to marginal marine units for the onshore Eocene succession in the Western Australian portion of the Eucla Basin; the Middle Eocene North Royal Formation and the upper Eocene Werillup Formation. Hou *et al.* (2006, 2008), mostly working on the stratigraphy of the eastern Eucla Basin, appears to have recombined the North Royal and Werillup Formations. Additional palynological age dating was not undertaken on samples from Western Australia and the age difference between the North Royal and the Werillup formations may still warrant a division of Eocene sediments into the two units. For this reason the work of Clarke *et al.* (2003, Table 2.2) is followed here.

Table 2.2 Stratigraphic units assigned to the Paleogene sediments of the onshore western Eucla Basin and marginal palaeovalleys of Clarke *et al*. (2003) and units used prior to Clarke *et al*. (2003).

Age	**Transgression**	**Prior to Clarke *et al.* 2003**	**Clarke *et al.* 2003**
late Eocene	**Tuketja**	Pallinup Formation, Princess Royal Spongolite, Hampton Sandstone	Pallinup Formation (Princess Royal Spongolite Member)
		Pidinga Formation, upper Werillup Formation, Wollubar Sandstone	Werillup Formation
middle Eocene	**Tortachilla**	Norseman Formation	Norseman Formation
		Hampton Sandstone, Pidinga Formation, lower Werillup Formation	North Royal Formation

The North Royal Formation includes clastics and lignites of middle Eocene age deposited in non-marine to marginal marine settings (Clarke *et al.* 2003). This unit is present along the western margin of the Eucla Basin and within marginal palaeovalleys. The formation amalgamates units previously referred to as the lower Pidinga and the lower Werillup Formations (Clarke 1993) as well as the Wollubar Sandstone (Kern and Commander 1993). The division of the Werillup Formation into an upper and lower unit by Clarke (1993) was based on the physical separation of the unit by the deposition of the calcareous Norseman Formation during the middle Eocene (McGowran 1989) Tortachilla transgression. Clarke (1993) assumed that the sediments below the Norseman Formation were of middle Eocene age and the sediments above to be late Eocene based on the presence of middle to late Eocene palynomorphs in both units (Parker 1988, Harris 1989). Further palynological work is required to confirm a division of the unit based on age. The North Royal Formation is an upward fining succession with lithic cobbles at the base, fining to sand then clay (Clarke *et al.* 2003). The uppermost parts of the unit are mainly lignitic, though significantly weathered in the type section. There is some ambiguity with the age of this unit, as the Lower *Nothofagidites asperus* Zone of Stover and Partridge (1973) to which Parker (1988) assigned the pollen assemblages of two samples, is middle Eocene. The division of the original Lower *N. asperus* Zone of Stover and Partridge (1973) into two zones, the Lower and Middle *N. asperus* Zones, by Partridge (1976) means it is highly likely that Parker's assemblages are more closely aligned with the Middle *N. asperus* Zone. Three of the Lefroy samples studied by Parker (1988) were aligned with the *Malvacipollis diversus* and *Proteacidites asperopolus* Zones of Stover and Partridge (1973). These zones are of Early to Middle Eocene age (Partridge 2006). A species list was not provided by Parker (1988) so the age assignments cannot be verified. The absence of the *M. diversus* and *P. asperopolus* Zones in numerous subsequent studies of Milne (pers. comm.) and her students (Al-Shawareb 2009, Mack 2012, Yew 2012) cast doubt on some of Parker's (1988) zone assignments.

The Werillup Formation comprises Late Eocene clastics and lignites marginal to the Eucla Basin in Western Australia (Clarke *et al.* 2003). It includes the former upper Werillup Formation (Clarke 1993), the Rollos Bore Formation (Playford *et al.* 1975) and the Wollubar Sandstone, and restricts the Pidinga Formation to equivalent units

on the eastern side of the Eucla Basin in South Australia. This amendment of the Werillup Formation allows for the inclusion of all lignites of Late Eocene age, namely those in palaeodrainages adjacent to the Eucla. Stover and Partridge (1982) dated an assemblage from the Werillup Formation, intersected in a drillhole near Albany, to the Middle *Nothofagidites asperus* Zone (Stover and Partridge 1973, Partridge 1976) of late Eocene age (Partridge 2006). Balme and Churchill (1959) assigned what was previously the Rollos Bore Formation a general Eocene age.

Terrestrial Eocene sedimentation in the Eucla Basin and the associated palaeovalleys was terminated by the Tuketja transgression, which deposited spicular sediments along the margins of the Eucla Basin (Clarke *et al.* 2003). All spicular sediments described from the Eucla Basin in Western Australia have been assigned to the Pallinup Formation, including the units previously called the upper Hampton Sandstone (Clarke 1993) and the Princess Royal Spongolite Member. Cockbain (1968) described the unit as a spicular siltstone, sandstone and mudstone grading into spiculite. The presence of the benthic foraminifera *Maslinella chapmani* from north of Balladonia dated the Pallinup Formation to the P14–15 zones (late middle to early late Eocene), possibly the P16–17 (latest Eocene to early Oligocene) zones (Fig. 2.3) (Clarke *et al.* 2003). This was considered as evidence of deposition during the Middle to Late Eocene, but the P14–17 range means it could have been deposited later.

2.2.2 Perth Basin

The Perth Basin sediments of Paleogene age, the Kings Park Formation and its Como and Mullaloo Sandstone members, are significantly removed both in terms of distance and lithology from the stratigraphy discussed in this work, and each warrants only a brief outline within this review. The Kings Park Formation, as defined by Quilty (1974) is preserved in a deep channel structure that has been incised into the Cretaceous and Jurassic sedimentary units of the Perth Basin (Davidson 1995). It unconformably overlies the Mesozoic sediments and has an unconformable contact with overlying surficial sediments (Davidson 1995). The Kings Park Formation consists of grey, calcareous, glauconitic siltstone and shales.

Playford *et al.* (1976) suggested that it is a shallow marine to estuarine infill of a drowned river valley. The two sandstone members, the Como and the Mullaloo, occupy what are potentially secondary channels that have been eroded into the base (Como) and near the top (Mullaloo) of the shales making up the Kings Park Formation. The Como Sandstone Member comprises fine to coarse-grained, moderately sorted, subangular to subrounded, pale grey to pale greenish grey, slightly clayey sand (Davidson 1995). The Mullaloo Sandstone Member is a poorly sorted, fine to very coarse-grained, pale brownish green, slightly glauconitic and clayey sand (Quilty 1974). Both sandstone members are suggested to be deposited in marine channels, with the Como Sandstone channel of only limited extent (Davidson 1995). The incision of these sediments, however, cannot be confirmed as Commander (2003) noted that an unconformable relationship has not been demonstrated. The glauconitic and calcareous nature of the sediments in the Perth Basin are much different from the sediments described earlier in this review for the inland palaeovalley systems.

A Palaeocene age has been assigned to the Kings Park Formation based on a foraminiferal assemblage studied by multiple workers (Coleman 1952, McGowran 1964, Quilty 1974, Haig *et al.* 1993). Parr (1938) described foraminifera from the Kings Park Formation and assigned an Eocene age. This age was confirmed by Coleman (1952) but changed to Palaeocene based on further study by McGowran (1964). Quilty (1974) noted that onshore, the sequence was solely of Palaeocene age (P4 – *Globorotalia pseumodenardii* Zone). Haig *et al.* (1993) noted the stratigraphic importance of a foraminifera described by Parr (1938) for dating upper Palaeocene sediments, with *Globorotalia chapmani* noted as an index fossil by several studies (McGowran 1964, 1968; Stainforth *et al.* 1975; Berggren 1977; Toumarkine and Luterbacher 1985; Banner 1989).

2.3 Palaeodrainages

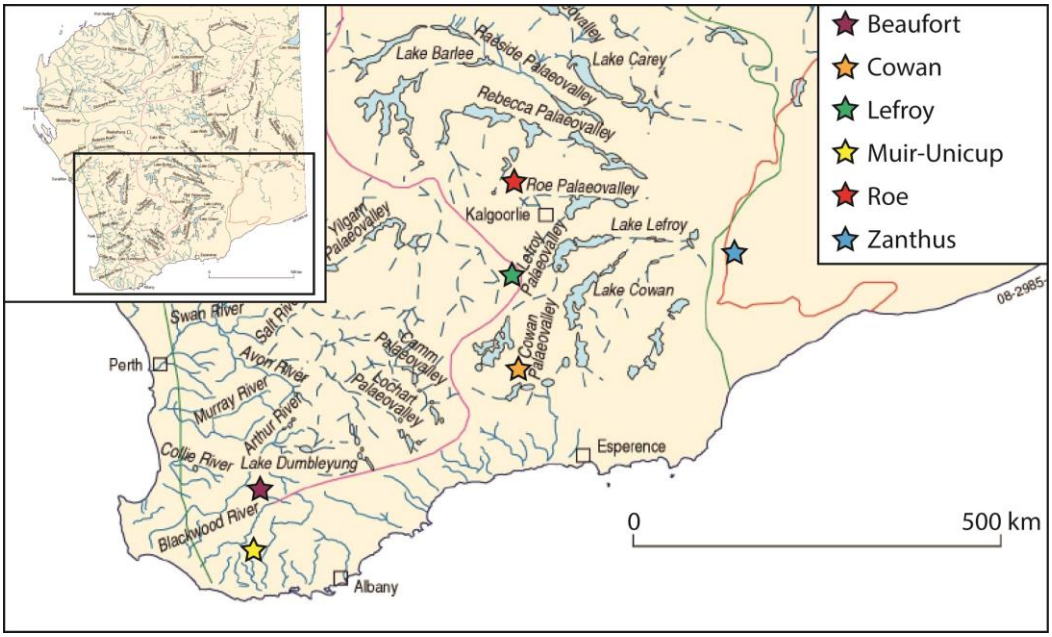


Fig. 2.2 Location of major palaeodrainage systems in southern Western Australia (adapted from Magee 2009)

Palaeovalley networks (Fig. 2.2) are extensively developed over much of Western Australia, draining the major pre-Palaeozoic cratons, as well as the Canning and Officer basins (Magee 2009). The widths of individual valleys in these systems range from a few tens of metres to more than 30 km and reach depths of up to 100 m (Hou 2001). In numerous instances, Cenozoic valleys have inherited older Mesozoic drainage patterns (Kern and Commander 1993, De Broekert and Sandiford 2005). Many sources (McGowran 1989, Middleton 1990, Clarke and Alley 1993, Clarke *et al.* 2003, Magee 2009) link Paleogene and early Neogene sedimentation in these older drainage systems with the separation of Australia and Antarctica. Significant valley scouring occurred at this time and removed the majority of older sediments. This left a legacy of Paleogene to Neogene sedimentation (Magee 2009, Table 2.1), as marine transgressions raised the base level in these drainages (Kern and Commander 1993). Significant flow ceased by the late Miocene (Hocking and Cockbain 1990). The systems today are preserved as subtle branching depressions in the land surface, though much has been overlain with Quaternary sediment (Hou 2001). Eocene sediments occur in both eastern (Beaufort) and western draining palaeovalleys (Lefroy, Cowan, Roe, Zanthus, Muir-Unicup) (Fig. 2.2).

2.3.1 East-draining palaeovalleys

The most well studied palaeovalleys of Paleogene age in southern WA, the Lefroy, Cowan and Roe, are eastern draining and marginal to the Eucla Basin. The Eucla/Bremer Basin and the eastern draining palaeovalleys share a similar lithostratigraphy, with the formations of the Eucla applied to the lithology of the eastern palaeovalley fills. Van de Graaff *et al.* (1977) originally named the Lefroy Palaeovalley, part of a two to five km wide, shallow drainage system located just south of Kalgoorlie (Jones 1990). This system also includes the Cowan Palaeovalley. Hos (1975) assigned a maximum thickness of 100 m of sediments in the Lefroy Palaeovalley to the Pidinga Formation (Werillup Formation of Clarke *et al.* 2003), describing them as laminated silts, clays and lignite, with local coarse carbonaceous sand bodies and common pyrite. Clarke (1993) described the overlying unit as fine to gravelly quartz sand and assigned it to the Hampton Sandstone. The Hampton Sandstone was subsequently restricted by Clarke *et al*. (2003) and is now only used for the original unit, a calcareous marine sand underlying the Late Eocene Wilson Bluff Limestone. The sand in the Lefroy Palaeovalley was included within the Werillup Formation. Hos (1975) dated this unit as no younger than late Eocene based on the ranges of pollen species known to be restricted to the Eocene elsewhere in Australia (Harris 1971), but found the age of the base of the unit harder to determine, stating that it may extend into the middle Eocene. Dinoflagellates found in all but the lower four samples support an upper Eocene age. Hos (1975) was unable to correlate the samples with eastern zonation schemes, with only a few species from the Otway Basin zones of Harris (1971) present, and these being of limited stratigraphic value. A correlation of the spore-pollen assemblages with the zonation scheme of Stover and Partridge (1973) was not attempted (Hos 1975). Itzstein-Davey (2004) dated an additional seven samples in the Africa open cut mine in the Lefroy Palaeodrainage system to the Middle *Nothofagidites asperus* Zone (Stover and Partridge 1973), of late middle to late Eocene age. At its westernmost boundary the Lefroy Palaeovalley connects to the former Bremer Basin and contains carbonate sediments assigned to the Bremer Basin sequence of Playford *et al*. (1975). The North Royal Formation is absent from the Lefroy Palaeovalley. The Cowan Palaeovalley includes the lignitic

and carbonaceous sediments of the North Royal and Werillup Formations, separated by the Norseman Limestone (Clarke 1993, Clarke *et al.* 2003).

The Eocene nomenclature described by Clarke *et al.* (2003) extends to the Roe Palaeodrainage slightly east of Kalgoorlie. The Wollubar Sandstone of Kern and Commander (1993), described for the basal unit in the Roe Palaeodrainage, is now divided between the North Royal Formation and the Werillup Formation. Clarke *et al.* (2003) recommended that the Wollubar Sandstone be abandoned as the unit is often not a sandstone and, where unweathered, resembles the Werillup Formation in that it is carbonaceous and interbedded with clays. The base of the North Royal Formation in the Roe palaeodrainage is frequently conglomeratic, with pyrite found at the base in one bore (Kern and Commander 1993). Lithological variation in the unit is associated with the morphology of the palaeochannel, with beds of clay and sandy clay more frequently intersected at the sides of the channel. Thin beds of carbonaceous silt and lignite are less frequent, but are also linked with channel sides to the east. Backhouse (1989) dated the Wollubar Sandstone to the Middle *N. asperus* Zone, the late Eocene age correlating this particular interval to the Werillup Formation. The upper unit defined for the Roe Palaeodrainage, the Perkolilli Shale, is significantly weathered and likely of Neogene age (Clarke *et al.* 2003).

Milne (1988) reported a palynoassemblage from fluvial to paludal sediments with a minor marine influence from a palaeoestuary at Zanthus, on the western margin of the Eucla Basin. The lithology of the Zanthus sediments places them within the late Eocene Werillup Formation (Clarke *et al.* 2003). The Zanthus palynoassemblage was correlated to the Upper *Nothofagidites asperus* Zone of the Gippsland Basin (Stover and Partridge 1973) and the Otway Basin late Eocene *Sparganiaceaepollenites barungensis* spore-pollen zone (Harris 1971). The Upper *N. asperus* Zone, and the dinoflagellate *Spiniferites ramosus* Zone (Harris 1985), to which the assemblage was also aligned, are now considered early Oligocene in age based on amendments to the standard palynozonation scheme by Partridge (2006). Milne (1988) recognised that correlation to the standard zonations established for eastern Australia was difficult, with species from the middle Eocene Lower *N. asperus* Zone through to the mid-early to middle Oligocene *Proteacidites tuberculatus* Zone of Stover and Partridge (1973) found within the same assemblage. The palynoassemblage at Zanthus is likely

equivalent to the Mulga Rocks assemblages, but further study of the marine component is needed to confirm this.

2.3.2 West-draining palaeovalleys

The west-draining palaeovalleys of southern Western Australia typically exhibit flattened bases and low gradients. The Beaufort Palaeovalley (Fig. 2.2) is infilled with 60 to 70 m of late middle to late Eocene sediment, divided into a lower fluviatile unit and an upper lacustrine unit (Waterhouse *et al.* 1994). The lower unit consists of dark brown and grey, carbonaceous, rounded to sub-rounded sand, clayey sand and clay constrained within a relatively narrow, 200 to 500 m wide, channel, which directly overlies Archaean bedrock. The laterally variable sediments assigned to the lower unit are interpreted to reflect a range of localised environments associated with a meandering river system (Magee 2009). Well-preserved pollen assemblages (Waterhouse *et al.* 1994) correlate with the Middle or Upper *N. asperus* Zones of Stover and Partridge (1973) and Partridge (1976), and are broadly similar to those reported from Zanthus (Milne 1988) and in boreholes near Albany (Stover and Partridge 1982). The upper lacustrine unit was dated as Miocene (Waterhouse *et al.* 1994). The lithostratigraphy of other western-draining palaeovalleys containing sediments of potential Eocene age has not been fully described.

The Muir-Unicup Catchment, located on the south coast of WA and 300 km south of Perth, is an unusual case in that it is west-draining but contains sediments to which the Eucla Basin lithostratigraphy can be applied. Previous studies have defined it as an inset-valley, mostly incised into the Proterozoic Albany-Fraser Orogen, with a small north-east extension onto the Yilgarn Craton (Chakravartula and Street 2000; De Silva 2000, 2004; Smith 2003, Smith and Hearn 2006). The palaeorivers draining this area are thought to have flowed south, though west-east meanders have been recognised (Beard 1999, Smith and Hearn 2006). Regardless of palaeodrainage direction, De Silva (2000, 2004) and Smith (2003) have assigned the sedimentary units present within the Muir-Unicup inset-valley to the lithostratigraphy outlined for the Eucla Basin by Clarke *et al.* (2003). The middle Eocene North Royal Formation is not present, with sediments of the Werillup Formation directly overlying

crystalline rocks. Lignitic samples from the Werillup Formation in the Muir-Unicup Catchment have been assigned to the late Eocene Middle *Nothofagidites asperus* Zone (Milne 2003, Al-Shawareb 2009, Yew 2012).

2.4 Study area

The study area is situated on the northeast margin of the Yilgarn Craton and incised into the Officer and Gunbarrel basins (Fig 2.3). Fewster (1999) describes the study site as the 'Narnoo Basin', but it is not yet formally recognised as a basin by the Geological Survey of Western Australia. Douglas *et al.* (2011) instead identifies a complex of palaeochannels within a tectonically controlled feature that has since been referred to as the Narnoo Palaeovalley (Mack and Milne 2015 in Chapter 8). This palaeovalley is bounded by the Archaean rocks of the Yilgarn Craton along the southwest and northwest margins, and by the Proterozoic Albany-Fraser Province in the southeast (Fig. 2.3). The Narnoo Palaeovalley is mostly underlain by Late Palaeozoic and Mesozoic sediments of the Gunbarrel Basin and separated from the Eucla Basin by the Streich Ridge (Fewster 1999); a ridge of metamorphosed sedimentary rocks belonging to the Albany Fraser Orogen. The sedimentary infill is primarily of late Eocene age (Mack and Milne 2015), with some Cretaceous clays (Islam 1983). Units above the water table, that have been heavily oxidised, may range from middle to late Miocene to Pleistocene (Fewster 1999). The entire sequence is buried beneath the Quaternary sand dunes of the Great Victoria Desert.

2.4.1 Exploration history

The original operators of the Mulga Rock tenement (Fig. 2.3), the Petroleum and Nuclear Corporation Exploration Pty Ltd (PNC), drilled 1,600 drill holes (diamond and rotary core) from 1978 to 1990 as part of a widely spaced reconnaissance drilling program looking for sandstone-type uranium deposits (Inwood 2009). The uranium deposits of the Mulga Rock Project were discovered in 1979. From 1989 to 1991 Eaglefield Holdings Pty Ltd drilled 250 shallow air-core holes in nearby tenements, focussing on discovering heavy mineral sand deposits. They drilled an additional 260 holes from 1993 to 1999 with a focus on gold. Their focus broadened from 2003 to

2007 with drilling, metallurgical studies, geophysics and geological studies aimed at discovering multi-element commodities. In 2007 Energy and Minerals Australia (EMA) acquired the tenement over the Mulga Rock Project, with the aim of delineating the uranium resource. In 2015 EMA changed its name to Vimy Resources Limited.

2.4.2 Local geology

The Mulga Rock Uranium Project is located approximately 250 km east-northeast of Kalgoorlie within the Narnoo Palaeovalley (Fig. 2.3). Exploration in the tenement is focussed on lenses of lignite which contain a rich palynoflora (Mack and Milne 2015) and are associated with an economically significant uranium deposit.

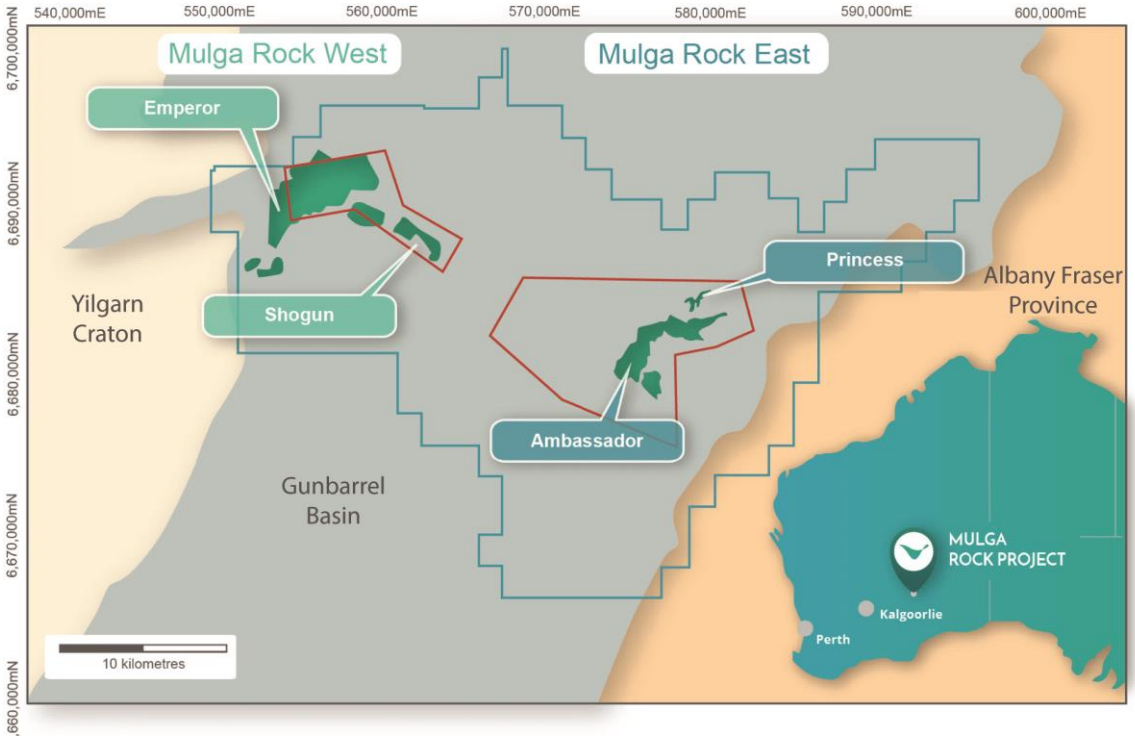


Fig. 2.3 Location of the Mulga Rock Uranium Project within Western Australia and the Gunbarrel Basin. The blue outline marks the boundaries of the tenement.

Four separate uranium concentrations have been recognised; Shogun, Emperor, Ambassador and Princess (Fig. 2.3).

2.4.3 Lithostratigraphy

Terrestrial conditions in the Narnoo Basin have persisted since the Cretaceous (Douglas *et al.* 2011). Significant weathering occurred during the Oligocene to mid Miocene during a period of humid, tropical climate, and the units overlying the water

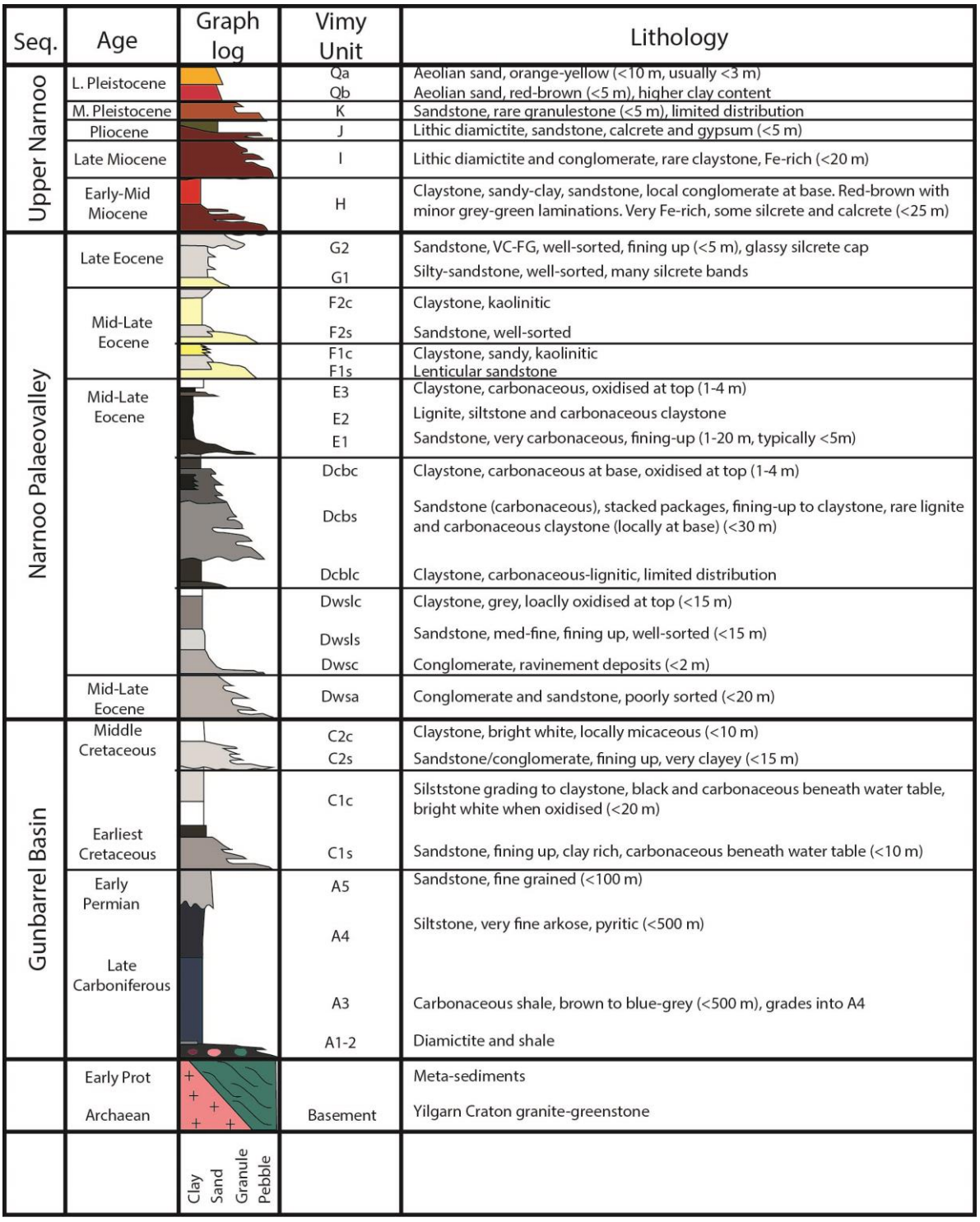


Fig. 2.4 Generalised stratigraphy of the Narnoo Palaeovalley (from EMA pers. comm. 2016). Colours are a representation of colours observed during logging of drill core.

table are heavily oxidised. Douglas *et al.* (2011) recognised two major packages of sediments below the oxidised zone; an upper clay rich interval and a lower sand. Fewster (1999) divided the same sediments into eleven units. This has been expanded, with the addition of a number of subunits, during exploration of the basin by EMA (now Vimy Resources) (Fig. 2.3). An informal alpha-numeric nomenclature has been employed to name these successions, with formalisation requiring further age dating and lithological studies of most units. These units are grouped into three sequences: the Upper Narnoo Sequence inclusive of units Qa to F, the Narnoo Basin Sequence from E to D and the Gunbarrel Sequence inclusive of A through C (Fig. 2.4).

Several units within the Narnoo Palaeovalley have been recognised as stratigraphically equivalent to rocks within the Eucla Basin, though the sediments of the Narnoo are terrestrial compared to the shallow marine to continental margin sediments of the Eucla Basin. Unit E was suggested to be equivalent to the Werillup Formation of the western Eucla Basin (Fewster 1999). Fewster (1999) also suggested a relationship between Unit D and the Hampton Sandstone.

2.4.4 Mineralisation

The Mulga Rock Deposits of the Narnoo Basin are of significant economic importance. Three uranium deposits hosted by the lignitic interval (E2) have been recognised, along with the potential for gold and base metal deposits. Of significance to current mining operations is the E2 interval that has been estimated to contain up to 1,400 ppm uranium (Fulwood and Barwick 1990) and averages between 500 to 630 ppm within individual mineralisation zones. Uranium is hosted by peat and clayey peat intervals that occur directly below the redox boundary at the base of the weathered zone. The main period of uranium mineralisation has been dated to latest Miocene to Pliocene (Fewster 1999). In addition to the lignite hosted uranium, a further four types of mineralisation (lignite hosted nickel/cobalt; sandstone hosted nickel-cobalt and localised uranium; sandstone hosted, fault associated uranium with low grade gold; and sandstone hosted gold) are recognised within the Narnoo Sequence (Table 2.3).

Table 2.3 Mineralisation recognised within the Narnoo Basin and intervals of occurrence (from Inwood 2009).

Mineralisation Type	Stratigraphic Interval	Comments
Lignite hosted uranium/polymetallic	E2	Adsorbed to organic matter, rare discrete minerals
Lignite hosted nickel/cobalt	E1	
Sandstone hosted nickel-cobalt and localised uranium	Dcb	
Sandstone hosted, fault associated uranium with low grade gold	Dwsl	
Sandstone hosted gold	Dwsa	Low grade, sheet-sandstone at or near base of Narnoo sequence

2.4.5 Intervals studied

The focus of this study is on Paleogene palaeovegetation and palynostratigraphy (Chapter 3) and, for this reason, samples have been collected from the section Vimy consider to be Eocene, inclusive of units D and E. The intervals underlying D are of Cretaceous age, and those overlying E are significantly oxidised. All subunits (Fig. 2.4) were included in the study, except for the Dwsc interval. A particular focus was on the E2 lignite as the lithology of the unit was considered most likely to yield a rich palynoflora.

3. Literature review – Paleogene palynology, palaeobotany and palynostratigraphy in southern Australia

3.1 Introduction

Palynology and palaeobotany provide information about the local and regional vegetation at the time sediments were deposited. Palaeobotany studies those parts of a plant that are large enough to be seen without magnification; fossilised wood, roots, fruits, leaves and most significantly, cuticle. Palynology is the study of microscopic remains of plants, including spores, pollen and charcoal as well as other acid-resistant organisms such as dinoflagellates, acritarchs and chitinozoans, and is an important biostratigraphic tool for dating and correlating sedimentary rocks for petroleum, mineral and groundwater exploration.

Plant macrofossils typically provide information about the local vegetation. Their size and relatively delicate nature means they are generally not transported far from their parent plant. In contrast, microscopic pollen and spores are dispersed widely by wind, water and animal vectors and provide information about past vegetation on both a local and regional scale. Pollen and spore walls are composed of sporopollenin, an acid-resistant biopolymer. The chemical resistance of the outer layer of pollen grains and spores means that they are transported and preserved in a similar way to sedimentary particles. A combination of palaeobotanical and palynological studies provides the best picture of the past vegetation.

In southern Australia, thick successions of carbonaceous sediments are present in the Gippsland, Murray and Otway basins. The age ranges of multiple spore and pollen species from the Cretaceous to the Neogene in these basins define biostratigraphic zonations that are used throughout the country to relatively date sedimentary rocks. Smaller palynostratigraphic studies have also been completed in eastern parts of the Eucla Basin and at dispersed sites such as the Southern Monaro Area and the Lachlan River Region in the highlands of New South Wales.

Palynological studies of Paleogene sediments in southern Western Australia (WA) are limited in comparison with those of southeastern Australia. In WA, sediments of this age occur in the southern part of the Perth Basin, the southern coastal regions (Bremer Sub-basin, the Muir-Unicup catchment), the margins of the Eucla Basin, and in palaeochannels incised into the Yilgarn Craton and extending into a palaeovalley in the Cretaceous Gunbarrel and Permian Officer basins. These sediments are geographically isolated, limited in vertical extent, and generally represent only a single period of deposition (i.e. late Eocene, middle Eocene). The Eocene of WA is the most studied epoch, with minimal studies completed on the Paleocene Kings Park Formation in the Perth Basin. No sediments have been palynologically dated as Oligocene in WA.

Southern Western Australian Cenozoic palynofloras are similar, but not entirely consistent with, the palynofloras used to construct the standard zonations established for eastern Australian basins, and a stark provincialism is apparent between east and west. This review will note the peer-reviewed published palynological and palaeobotanical studies that have been conducted on Cenozoic aged sediments of southern WA, with emphasis on the Paleogene, in the context of southern Australia as a whole. It will then discuss the differences between the southern WA and southeastern Australian Paleogene vegetation and biostratigraphy, and the problems that have arisen from these differences.

3.2 Previous studies of palynoflora

3.2.1 Introduction

Major palynological studies in southern Australia were largely completed prior to 2000. Isabel Cookson pioneered the field in Australia, commencing in 1945 with the first publication in a career of 35 sole author papers and 50 co-authored papers. Cookson (1945) reported the first Cenozoic fossil pollen records from Victoria, and to a lesser degree, WA, New South Wales, South Australia, Queensland and Tasmania. Cookson (1947, 1950) and Cookson and Pike (1954) named and described the first of many fossil pollen species present in southern Australian sediments, and

discussed the relationships that these palynomorphs had to extant plant families and genera. Other works completed by Cookson and colleagues included studies of lignitic intervals in core holes from Lake MacDonnell and Pidinga (Pike 1949, 1950) and the Comaum bore hole in South Australia (Cookson 1953a, Harris & Cookson 1965). The earliest palynostratigraphic work focused on a microflora from the Birregurra No. 1 bore in the southwest of Victoria (Cookson 1954a).

The 1970s to the '90s saw a period of review of Cenozoic palynology, including Helene Martin's works (Martin 1978, 1981). Kemp (1978) summarised the Southeast Indian Ocean region as a whole. Other major reviews (e.g. Barlow 1981, Lange 1982) incorporated evidence of the Paleogene vegetation with cytogenic, cladistic and other phylogenetic studies. This period of summary was exemplified by Hill's (1994) *History of the Australian Vegetation: Cretaceous to Recent*. This included an introduction to the Australian fossil plant record (Hill 1994), as well as papers on Australian Cenozoic phytogeography (Martin 1994) and early Cenozoic vegetation (Macphail *et al*. 1994). Other summary papers from the early '90s include Martin (1990) and Truswell (1993). More recently, the Cenozoic vegetation of southern Australia was reviewed by Hill (2004) in a paper that discussed the origins of the present day flora, and was later included in a global analysis of Eocene vegetation patterns (Utescher and Mosbrugger 2007).

3.2.2 Victoria

Palynological studies in Victoria have been conducted in the Princetown area (Harris 1965), the onshore Otway Basin (Harris 1971) and the offshore and onshore Gippsland Basin (Stover and Evans 1973, Stover and Partridge 1973, Partridge 1976). Harris (1965) described four new genera and 31 new species, including several that may be considered index species for the Paleogene, from sands and clays in the Princetown area. Harris (1971) established 11 biostratigraphic units for the Otway Basin from the Palaeocene to the Pliocene. Three zones divided the Palaeocene and five the Eocene (Fig. 3.1). The age of each of these zones was further supported by correlation with planktonic foraminiferal zones (Harris 1971).

Stover and Evans (1973) processed more than 800 conventional and sidewall cores of Late Cretaceous to Late Eocene age in 40 wells drilled in the Gippsland Basin. Up to 1,200 metres of sediments were intersected in each well. Stover and Evans (1973) introduced the main characteristics of the palynoassemblages and defined seven palynostratigraphic zones. Four palynostratigraphic zones were defined for the Eocene and two for the Palaeocene (Fig. 3.1). A more thorough taxonomic and biostratigraphic treatment of the same palynoassemblages and palynozonation scheme was published by Stover and Partridge (1973), which described 10 new form genera and 65 new species.

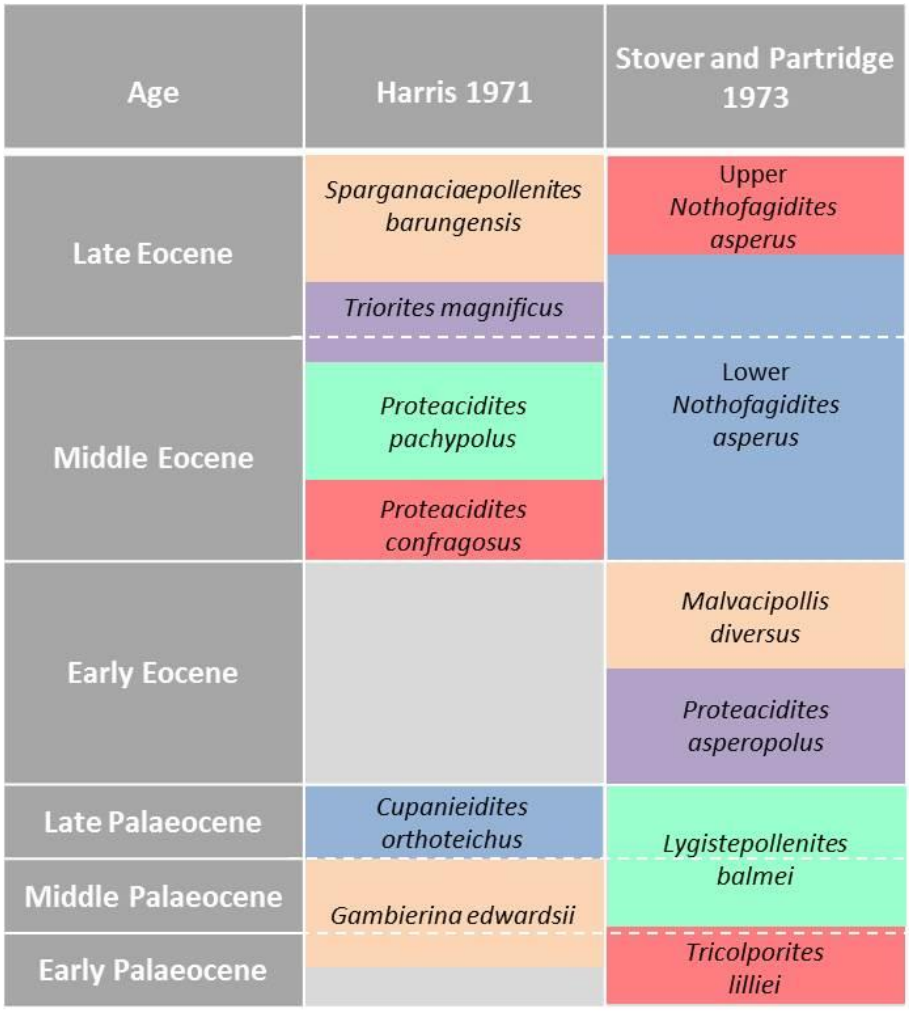


Fig. 3.1 Paleogene palynostratigraphic zones for sedimentary basins in Victoria; Otway (Harris 1971) and Stover and Partridge (1973)

3.2.3 New South Wales

In New South Wales, studies have been undertaken in the Murray Basin (Martin 1973a, 1973b 1977, 1984a, 1984b, 1984c, 1986, 1988, 1991, 1993a, 1993b, Macphail and Truswell 1989, Macphail 1999), the Southern Monaro area (Taylor *et al*. 1990), and Bungonia in the Southern Tablelands (Truswell and Owen 1988). Martin (1993a) recovered palynomorph assemblages from the late Eocene to the middle Miocene in the Mallee Cliffs bore, central Murray Basin. Dinoflagellates were present throughout the section allowing for the recognition of five zones/acmes that further constrained the age of the sediments. Martin (1973a, 1986, 1991) discussed the Cenozoic palynostratigraphy and history of the vegetation and climate in the Lachlan River Valley, using sediments ranging from late Eocene to Pliocene-Pleistocene age. A summary of the palaeovegetation of the Murray Basin was published by Martin (1993b), specifically covering the late Eocene to the middle Miocene. Approximately 100 bores were studied, totalling over 450 samples. Further papers by Martin include studies of palaeoecology and quantitative relationships (Martin 1984a), and stratigraphic palynology (Martin 1973b, 1977, 1984b, 1984c). Macphail and Truswell (1989) correlated palynological analyses for four fully cored boreholes in the central west Murray Basin.

Macphail (1999) outlined a palynostratigraphic scheme for the Murray Basin, analogous to that of the Gippsland Basin. A total of 400 samples (core and cuttings) were analysed from 45 boreholes throughout the Murray Basin. Comparison material was added from the Lachlan Valley and from the Darling Basin to the north. A total of 275 palynomorphs were identified and seven palynostratigraphic zones established (Fig. 3.2), ranging in age from middle Eocene to early Pliocene. Three zones delineate the Eocene, and are named for their equivalents in the Gippsland Basin (Stover and Partridge 1973, Partridge 1976).

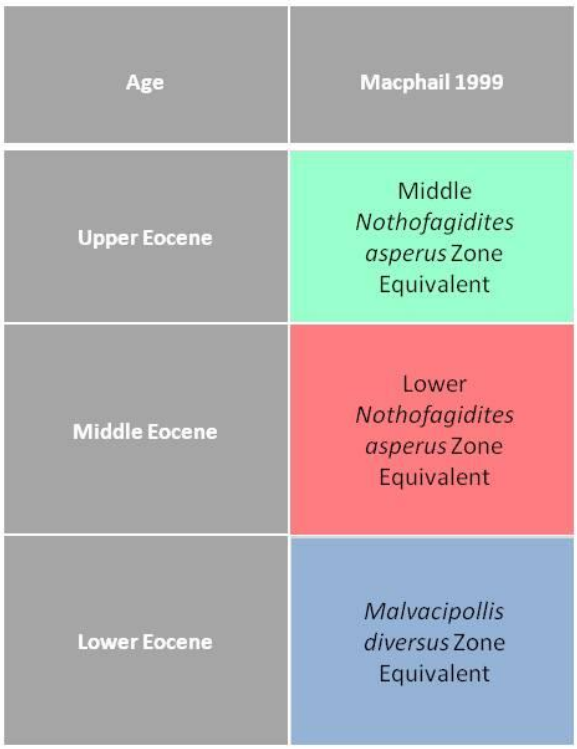


Fig. 3.2 Palynostratigraphic zones for the Eocene of the Murray Basin, as established by Macphail (1999). The ages remain as they were listed in the original publication.

Studies in the highlands of NSW have been published on palynofloras from the Southern Monaro Area (Taylor *et al.* 1990) and Bungonia (Truswell and Owen 1988) in the Southern Tablelands. Palynostratigraphic dating of sediments at Southern Monaro by Taylor *et al*. (1990) assisted in constraining the timing of the uplift of the southeastern Australian highlands. The study dated fluvial and lacustrine sediments, deposited prior to basaltic units associated with the uplift, as upper late Palaeocene. Pollen assemblages, and fossil wood preserved in the same sediments, indicate the presence of a cool temperate rainforest dominated by podocarps and araucarian conifers. A palynoassemblage from a site near Bungonia (Truswell and Owen 1988) contains 120 pollen and spore species assigned to the Lower *Nothofagidites asperus* Zone (middle Eocene). Thirteen new species were described, several of which represent the first recognition of several families (e.g. Arecaceae and Lamiaceae) in the Paleogene of Australia.

3.2.4 South Australia

South Australian studies include assemblages from the SADME Ooldea 6 drillhole (Alley and Benbow 1989) and the One Tree Hill Area, St Vincent Basin (Alley and Broadbridge 1992). Alley and Benbow (1989) studied an assemblage from a carbonaceous interval of the Pidinga Formation intersected in SADME Ooldea Range 6, a drillhole located along the eastern margin of the Eucla Basin and near the edge of the Nullarbor Plain. The palynoflora was dated as late middle Eocene to early late Eocene (Middle *Nothfagidites asperus* zone of Stover and Partridge 1973, and *Triorites magnificus* zone of Harris 1965). Alley and Broadbridge (1992) analysed Paleogene sediments encountered in the One Tree Hill Area, intersected in a sandpit and numerous boreholes at this site. A carbonaceous interval was dated as middle Eocene (Lower *Nothofagidites asperus* Zone of Stover and Partridge 1973).

3.2.5 Western Australia

Paleogene palynological studies in WA have been limited by the significant lateritic weathering occurring throughout the state during the Late Cenozoic. This further restricts the already patchy occurrences and limited vertical extent of the WA Paleogene sediments. Palynological analyses have been completed in the Bremer (e.g. Hos 1975, Stover and Partridge 1982, Al-Shawareb 2009) and Eucla Basins (Milne 1988, 1998, Milne and Martin 1998) as well as from palaeochannels incised into the Yilgarn Block (Balme and Churchill 1959, Churchill 1962, Waterhouse *et al*. 1994, Itzstein Davey 2004).

Bremer: The earliest studies including WA material are those of Cookson (1953b, 1954b) and Cookson and Pike (1953a, 1953b, 1954a, 1954b). These works described many of the commonly occurring dicotyledonous pollen types in Paleogene sediments and reported on four gymnosperm species from the Bremer Basin. Hos (1975) studied 17 sludge samples from the Werillup No. 17 bore, drilled near Albany. The palynoflora was diverse and included species that are characteristic of the present day Australian climate, with its marked dry season. Stover and Partridge (1982) dated the Werillup Formation in the Fitzgerald area as late middle Eocene to

early late Eocene. They recorded a number of southeastern Australian species in WA for the first time and described 13 new species.

Western Eucla: Milne (1988) produced the first published report on western Eucla Basin sediments and dated lignitic sediments in the Zanthus-6 boreholes as latest Eocene. This date was further constrained by the presence of a marine dinoflagellate assemblage comparable to the late Eocene to early Oligocene *Spiniferites ramosus* Zone. A total of 166 spore-pollen species were recognised. The Zanthus-6 palynoflora, along with assemblages from Balladonia-15 contributed to Milne's (1994, 1997, 1998a; Milne and Martin 1998) studies of Eocene proteaceous pollen that provide significant information about the palaeovegetation of southwest Australia. Milne (1998) described five new species from Zanthus and Balladonia.

Palaeodrainages: Balme and Churchill (1959) and Churchill (1962) described an assemblage recovered from lacustrine sediments on the Yilgarn Block, from a site near Coolgardie, which they dated as Eocene. Waterhouse *et al.* (1994) reported an assemblage they aligned with the Middle or Upper *Nothofagidites asperus* Zone of Stover and Partridge (1973) in newly recognised sediments of Eocene age in the Beaufort River palaeochannel. A diverse range of proteaceous pollen was noted, along with a similarity to coeval assemblages in the Bremer Basin and the western margin of the Eucla Basin.

Officer Basin: The southern Officer Basin is a site of more recent work on a rich palynoflora from an up to 80 m thick carbonaceous sequence of lignites, carbonaceous clays and sands dated as late Eocene (Mack 2011, Mack and Milne 2015). This assemblage is unique, in that many of the assemblages are dominated by palynomorphs affiliated with modern Myrtaceae. Proteaceous pollen is also diverse, similar to the palynoassemblages from both the Bremer (Stover and Partridge 1982) and Eucla basins (Milne 1988, 1998, Milne and Martin 1998).

3.3 Previous studies of macroflora

Palaeobotanic studies have been much more extensive in south-eastern Australia in comparison to southern WA, similar to the southeastern dominance observed for palynology. Studies commenced in the 1800's with the work of Mueller (1874, 1883), McCoy (1876) and Ettingshausen (1883, 1886, 1888). Work in the early 1900's was completed on macrofloras recovered from under 'auriferous drifts' or deep leads (Deane 1923, Chapman 1926a). Reports of macrofloras associated with coal deposits spanned the 1900's (Deane 1902, 1925, Paterson 1935, Cookson 1947, Cookson and Duigan 1950, Patton 1958, Duigan 1966). These researchers identified several important fossil sites from the Victorian High Plains and many close to Melbourne (Deane 1902, 1904, Patton 1928, Paterson 1934, Gill 1949, Gill and Baker 1950). Individual species of importance within these floras were identified, including *Eucalyptus* (Chapman 1926b), Casuarinaceae (Patton 1936), *Acacia* (Cookson 1954c), Banksieae (Cookson and Duigan 1950), cycads (Cookson 1953c), *Dacrydium* (Cookson and Pike 1953b) and other podocarps (Cookson and Pike 1953a, 1954). Only a few sites are included within this review as other syntheses providing summaries exist, including Christophel (1981, 1989, 1994), Christophel and Greenwood (1989) and Hill (1990, 1992). Further catalogues of the significant body of work on Victorian macrofloras include Duigan (1950) and Hill (1988a).

3.3.1 Victoria

Paleogene aged macrofossil studies from the Otway Basin in Victoria have been completed on material from Deans Marsh, Anglesea and the surrounding area. Deans Marsh is of early Eocene age and a total of 128 leaves have been analysed by multiple workers (Christophel and Greenwood 1989, Christophel 1994, Greenwood 1994, Greenwood and Wing 1995). The Anglesea macroflora has been under study since Douglas (1977) first reported the site. Numerous studies (Hill 1978, 1980, Christophel 1980, 1981, Greenwood 1987, Hill and Christophel 1988, Rowett and Christophel 1990, Rozefelds 1988, Rozefelds *et al.* 1991) have been published on abundant, taxonomically diverse and well-preserved plant fossils (leaf, fruit, flower and cones) derived from a series of fluvio-lacustrine lenses from the Anglesea open-

cut brown coal mine. The associated microflora has also been studied and indicates a middle to late middle Eocene age (Lower *Nothofagidites asperus* Zone of Stover and Partridge 1973).

Further Victorian Paleogene macrofossil material comes from the LaTrobe group in the Gippsland Basin, intersected in open-cut brown coal mines at Yallourn, Morwell and Traralgon. The age of these sediments span from late middle Eocene to early/middle Miocene depending on the location of the exposure studied. The late middle Eocene sediments are known from Traralgon. Fossil leaves, fruits and seeds, wood and *in situ* tree stumps have been described from sediments between the brown coal seams (Chapman 1921, 1925a, 1925b, Cookson 1947, Cookson and Duigan 1950, 1951, Cookson and Pike 1953a, 1953b, 1954, Pike 1952, Patton 1958, Duigan 1966). Other publications covering these coal seams include Blackburn (1985) and Barton *et al*. (1995).

3.3.2 South Australia

A middle Eocene megafossil flora is known from Nelly Creek in the far north of South Australia (Christophel *et al*. 1992). A total of 269 leaves were collected from a clay within the Eyre Formation. Eleven of 16 parataxa identified can be allied with extant families, including Proteaceae, Myrtaceae, Araucariaceae, Podocarpaceae, Casuarinaceae and Lauraceae. When compared with coeval floras, the Nelly Creek flora is noted to be taxonomically distinct and physiognomically more sclerophyllous.

3.3.3 Western Australia

Bremer Basin: Leaf fossils are known from the Bremer Basin, with the Werillup Formation lignites and mudstones locally rich in plant material. McNamara (1992) described lignitic *Banksia*-type fruits, recovered west of Walpole, along with possible myrtacean fruits that may have been derived from the Werillup Formation, found in Nornalup. The coeval Werillup Formation (previously Pidinga), deposited in palaeodrainage channels in the Norseman-Kalgoorlie district, has yielded

proteaceous leaf cuticles (Lange 1978, Carpenter *et. al.* 1995). Also from the Bremer Basin, the late Eocene Pallinup Siltstone preserves a macroflora of mostly dicotyledonous leaves, in shallow marine sediments near Mt Barker, Cape Riche and Twertup (McLoughin and Hill 1996). One species of *Agathis* and *Nothofagus* and two of *Bombax* have been described (Chapman and Crespin 1934). McNamara (1992) noted impressions of a cycad pinnule, *Gymnostoma* fruits, and *Banksieaeformis*, *Agathis*, *Nothofagus* and other angiosperm leaves in collections that still require study.

Palaeodrainages: Carpenter and Pole (1995) studied 42 cuticle samples from late Eocene sediments in the Cowan and Lefroy palaeodrainages. Cuticle of dispersed conifer, *Nothofagus*, Cunonieaceae, Lauraceae and *Gymnostoma*, plus high diversities of myrtaceous and proteaceous cuticle-types have been identified from Werillup Formation in this location. More than 12 Proteaceae taxa were recognised, indicating a rich proteaceous component in the late Eocene macrofloras of WA.

The late Eocene Kojonup flora (McLoughlin and McNamara 2001) derives from the Kojonup Sandstone, which is preserved in palaeodrainage channels in the south-west of the Yilgarn Craton. The best representations of the unit are located in the Kojonup, Calingiri and Walebing areas, where abundant plant impressions and petrifactions have been recovered (Wilde and Backhouse 1977). The late Eocene age is derived from floral similarities with the Pallinup Siltstone and the correlation of strong silicification of the unit with similar siliceous cements and biogenic silica in other units of upper Eocene age (Clarke 1993). Carpenter *et al*. (2014) described a *Banksia* affiliate from this flora.

Hill and Merrifield (1993) described 35 taxa, mostly leaves, from the middle Eocene to Oligocene leaf deposits from West Dale, located in the south-west of WA. While floristically similar with macrofloras of similar age in south-eastern Australian basins, the West Dale flora is unique in that it is dominated by Myrtaceae and, to a lesser extent, Proteaceae. Also remarkable is the preservation of the leaf surface in this deposit, with little to no loss of detail.

3.4 Southeastern Australian palaeovegetation

3.4.1 Palaeocene

Evidence from Palaeocene sediments in southeastern Australia indicates that many of the characteristic elements of the modern Australian flora were already established by the early Cenozoic. Kemp (1981) interpreted the Palaeocene vegetation of Australia to be a complex temperate rainforest. Many of the Cretaceous plant species identified in Australia also continued into the Palaeocene (Dodson *et al*. 2002). The percentage of gymnosperms peaked in the early part of the epoch (Dodson *et al*. 2002) and angiosperms were present as a fairly diverse understory of shrubs (Truswell 1993). The palynological record shows that conifers, Araucariaceae and Podocarpaceae were a significant part of the vegetation along with Proteaceae and lesser amounts of Casuarinaceae, Myrtaceae and Fagaceae (Duigan 1966). Hill (2004) recognised that conifers dominated the southeastern highlands palaeoflora. Macphail *et al*. (1994) noted little difference in the lowlands, thus little altitudinal zonations were apparent during the Palaeocene. The presence of *Dacrydium* within these assemblages indicates a cool, moist, temperate climate, similar to that in which the genus survives today. Macrofossil deposits show a domination of Lauraceae in a palaeoflora interpreted to be a high diversity mesothermal-megathermal humid rainforest (Greenwood 2000). The proteaceous component is represented in the macrofossil record by large-leaved forms that have an affinity with extant species in meso-megathermal rainforests in northeastern Queensland. Other leaf forms have a resemblance to modern *Banksia*, including the sclerophyllous features that are characteristic of the family.

Nothofagus (Fagaceae) was rare, but widespread, with low frequencies in pollen assemblages (up to 10%) (Martin 1981). This could indicate that *Nothofagus* was growing at some distance from the depositional sites studied, or that the parent plants were rare in the Palaeocene vegetation. By the late Palaeocene, the palaeovegetation of southeastern Australia became Cunoniaceae-dominated simple closed forest that probably still contained a significant coniferous component (Martin 1981).

3.4.2 Eocene

Microfloras of the early Eocene indicate a replacement of the Palaeocene conifer and Cunoniaceae-dominated forests with diverse angiosperm multistratal rainforests (Greenwood *et al*. 2000). The early Eocene vegetation also showed a change from the dominance of Cunoniaceae recognised in the late Palaeocene to outright dominance by Myrtaceae. Sluiter (1991) interpreted this change as a major expansion of more complex closed forest within southern Australia. Pollen assemblages from the south east of the continent have revealed a number of pollen types showing a clear affinity to modern taxa of a tropical distribution, including the high abundance of Myrtaceae, Cupanieae, Malvaceae, Bombacaceae, *Beauprea*, *Anacolosa* and the mangrove palm *Nypa* (Kemp 1981). The mangroves from which the *Nypa*-like pollen was likely to be derived were prominent within coastal environments of southern Australia (Greenwood *et al*. 2000). Gymnosperms in the early Eocene were relatively sparse and *Nothofagus* was subordinate.

The middle Eocene of southeastern Australia is characterised by simple closed forests that represent a major floristic change from the earlier part of the epoch. From the pollen record, it appears that these closed forests were mainly composed of Myrtaceae, Cunoniaceae and *Brassospora* affiliates (Macphail *et al.* 1994). The early/middle Eocene boundary is marked by an increase in the representation of the *Nothofagus* genus, particularly *Brassospora*, along with a significant increase in Casuarinaceae (Truswell 1993). The importance of Cunoniaceae, Myrtaceae and the conifers decreased. The macrofossil sites of similar age lack evidence supporting the *Nothofagus*-Proteaceae-Myrtaceae dominated vegetation suggested by the microflora. The earliest discovered leaves of *Nothofagu*s are from the late Eocene, and affiliates of *Brassospora* are not known before the Oligocene (Hill 1987, 1991). For example, the Maslin Bay palynoassemblage contained over 25% of pollen types with affinities to Proteaceae and *Nothofagus*, but yielded only one leaf whose venation bore a resemblance to *Nothofagus* and only a proteaceous element of <1% (Christophel and Blackburn 1978). No myrtaceous leaf or cuticle was discovered, despite a contribution of 5% to the pollen spectra. The Nerriga assemblage, located in the southern tablelands of New South Wales also lacked leaves of *Nothofagus* or

Myrtaceae, with only one or two of proteaceous affinity (Christophel 1981). A conclusion can be made that the *Nothofagus* and associated genera may have been growing in areas away from the depositional site, thus removed from the catchment areas for the microfossils (Hill 1990), yet still remaining in close enough proximity to dominate the pollen suites. Scriven *et al.* (1995) described a leaf-type interpreted to be from a deciduous *Nothofagus* species in the Maslin Bay flora, implying that the trees were growing within or near the catchment. It is still undetermined whether this species belongs to the subgenus *Brassospora*, and the source of the abundant pollen of this type at this site is still unknown. The macrofossil assemblage at Anglesea revealed that the local vegetation may have been composed of abundant *Gymnostoma* (Casuarinaceae), with fossil representatives of *Diospyros* and *Musgravea* recognised along with numerous leaves of Lauraceae, Myrtaceae, Brachychiton, Elaeocarpus, Cunoniaceae, *Quintinia*, *Podocarpu*s and rainforest cycads and ferns (Truswell 1993). The vegetation of the late Eocene in southeastern Australia was likely to have remained a closed forest, with an extremely low content of light-demanding, low-growing plants recognised from deposits such as those of the Lachlan River Region (Martin 1986). Macphail *et al.* (1994) summarised these studies, stating that a *Nothofagus*-dominated rainforest was the prevalent vegetation for the time.

3.5 Southwestern Australia

3.5.1 Palaeocene

Studies of Palaeocene material in WA are limited, due to the paucity of known sediments of this age. Sediments deposited during the epoch are only known from the Perth Basin. Site 24 on the Ninetyeast Ridge, a site in the Indian Ocean to the west of northwest WA, suggests that the western half of southern Australia shared many species with southeastern Australia (Dodson *et al*. 2002).

3.5.2 Eocene

Middle to late Eocene palynological studies in Western Australia suggest significant provincialism in the vegetation of southern Australia (Hos 1975, Stover and Partridge 1982, Milne 1988, 1998). Early palynofloral studies (Hos 1975, Stover and Partridge 1982) relied on comparison with southeastern Australian palynoassemblages which were interpreted to represent a mesothermal *Nothofagus*-dominated rainforest. While WA palynofloras share similar elements with those southeastern Australia, the relative proportions of taxa differ (Dodson *et al*. 2002). At Zanthus, most of the taxa identified are shared with southeast Australia except for an extraordinary diversity of Proteaceae (Milne 1988). These same spectra have also contained *Acacia* pollen, marking the earliest record of the pollen type in Australia. In the Bremer Basin, similar Proteaceae-rich, *Nothofagus*-dominated palynoassemblages have been recovered (Hos 1975, Stover and Partridge 1982). Stover and Partridge (1982) described nine new proteaceous species from the Bremer Basin in the Fitzgerald area. Palynofloras from sites near Collie, Katanning and outside Manjimup have recorded similar plant groups, but in different proportions, with proteaceous types rare or absent and *Nothofagus* uncommon at 3 to 10% of the total pollen count (Milne pers. comm). This suggests that the vegetation of WA was regionally varied during the middle through late Eocene.

Adaptive features recognised as characteristic of the modern WA flora were also present or evolving during the Eocene: sclerophylly, a response to poor nutrient soils, and xeromorphy, a response to low water availability. Scleromorphic characteristics are in evidence at the West Dale site near Perth with many of the fossil species recorded as having thick leaves, as well as lacking rainforest adapted features such as drip tips (Hill and Merrifield 1993). Milne (1988) recognised a high relative abundance of *Petrophile*-like pollen in assemblages taken from sites dated as late Eocene in the western Eucla and Murray Basins. *Proteacidites cirritulis*, a small *Petrophile* affiliate, has been recognised to constitute up to 43% of the Proteaceae affiliates present in late Eocene assemblages from Western Australia and South Australian sites. This pollen type is indicative of the presence of sclerophyll communities akin to heath, woodland and/or dry sclerophyll (Milne 1998, Milne and

Martin 1998). *Banksia* and/or *Dryandra* leaves discovered at Kojonup, Calingiri and Walebing showed features that would have restricted water loss, with curled leaf margins recognised as some of the earliest evidence for xeromorphy in the continent (Dodson *et al*. 2002). The recent description of an unequivocally xeromorphic *Banksia*-like leaf from the Kojonup flora further supports the existence of xeromorphy in the late Eocene (Carpenter *et al*. 2014) of Western Australia. These palynological and palaeobotanical studies suggest that the palaeovegetation of southwestern Australia was locally and regionally more varied than that of the southern eastern Australia during the Eocene (McLoughlin and Guppy 1993, Milne 1988, 1998). Local evidence has shown that a mosaic of types was present with regional evidence indicating that the *Nothofagus*-dominated forests of the east were not so prominent in the west.

3.6 Southern Australian Cenozoic palynostratigraphy

The Eocene is the most studied epoch of the Cenozoic in Australia, with sites of this age producing rich palynofloras and well-preserved macrofossils. As deposition of sediment occurs, sequentially deposited pollen assemblages are incorporated within sedimentary strata (Dodson *et al.* 2002). The major boundaries between zones are defined by the presence or absence of indicator individual spore and/or pollen taxa, or by changes in the abundance of long-ranging common species in relation to the total pollen assemblage (Macphail 1999). To give this data some significance in the global scale, independent age control is provided by marine dinoflagellates whose stratigraphic distributions are linked to the international time scale. Chemostratigraphy and radiometric dating methods are also employed where available (Dodson *et al*. 2002).

All standard Cenozoic palynostratigraphic zonations constructed for southern Australia have been compiled from palynomorph assemblages from southeastern Australian sediments. The earliest work was undertaken by Cookson (1954a) in which she identified two Tertiary microfloras from the Birregurra No. 1 Bore in the southwest of Victoria. These microfloras were defined on the basis of the occurrence of *Triorites edwardsii* Cookson and Pike 1954 and *Proteacidites pachypolus*

Cookson and Pike in the “B” and “C” floras respectively. Harris (1971) reported that the index species of microflora C ranged from the Upper Palaeocene to at least the Upper Eocene, and for microflora B they ranged from the middle Pliocene to at least the mid Miocene. In the same paper, Harris constructed a palynostratigraphic scheme for the onshore Tertiary sediments of the Otway Basin (Fig. 3.1). This was followed by a more comprehensive study in the Gippsland Basin in the eastern Bass Strait by Stover and Partridge (1973), Stover and Evans (1973) and Partridge (1976). Partridge (1976), as well as Harris (1985), compiled dinoflagellate zonations for the Gippsland Basin and southern Australia respectively, and correlated these with the spore-pollen zonations of Harris (1971) and Stover and Partridge (1973). Due to the presence of a thick sedimentary sequence in the Gippsland Basin, it was possible to date and correlate successions from the Upper Cretaceous through to the Cenozoic. Macphail (1999) emended these earlier zonation schemes to fit the Murray Basin, an inland basin that covers parts of New South Wales, Victoria and South Australia (Fig. 3.2). Earlier Paleogene spore-pollen zonations for the Murray Basin include Martin (1984a) and Macphail and Truswell (1993). Partridge (2006, Fig. 3.3) updated the Australian Mesozoic and Cenozoic palynology zonations of the Gippsland Basin to the International Commission on Stratigraphy (ICS) 2004 Geologic Time Scale (Gradstein *et al*. 2004). The timeframe for many of the zones previously defined by Stover and Partridge (1973) and refined by Partridge (1976) were amended in this scheme (Fig. 3.4). Of significance to Paleogene palynostratigraphy is the change in age of the Middle *Nothofagidites asperus* Zone of Partridge (1976), that was formerly the upper section of Stover and Partridge’s (1973) Lower *N. asperus* Zone. Originally of early middle Eocene to early late Eocene age, it is now considered to be latest middle through late Eocene (Partridge 2006). Also changed was the lower boundary of the Upper *N. asperus* Zone, which was moved from late Eocene to the beginning of the Oligocene. The microplankton zones of equivalent age (Fig. 3.3) were also amended, with the *Spiniferites ramosus* Zone (Harris 1985) now considered to commence at the beginning of the Oligocene. This has ramifications for zone assignment, and therefore age, in studies prior to 2006 as the *S. ramosus* Zone was previously equivalent to both the upper part of the Middle *N. asperus* Zone as well as the lower Upper *N. asperus* Zone.

To date, a biostratigraphic scheme similar to those established in the east of southern Australia has not been compiled for the west. Compounding this difficulty is the limited vertical extent of sites studied to date. Instead, with minor modifications, the schemes derived from eastern sedimentary basins have been extrapolated to derive ages in several studies completed in the west of South Australia and in Western Australia (Cookson 1954b, Hos 1975, Milne 1988, Alley and Beecroft 1993, Alley *et al*. 1996). Problems arise due to diachronism in the times of first appearance and extinction of the index species defining the palynological zonations outside of the basins for which they were defined (Macphail 1999). For example, Alley and Beecroft (1993) identified *Acacia* pollen within sediments correlating to the Middle *Nothofagidites asperus* Zone, despite reports of the first appearance of the genus in eastern basins dated as Oligocene in age. Differences in the maximum relative abundance of some taxa between the east and west also has to be taken into account as well as the significance of species that have not been recorded or are too rare to be of use in the zonations of the eastern basins.

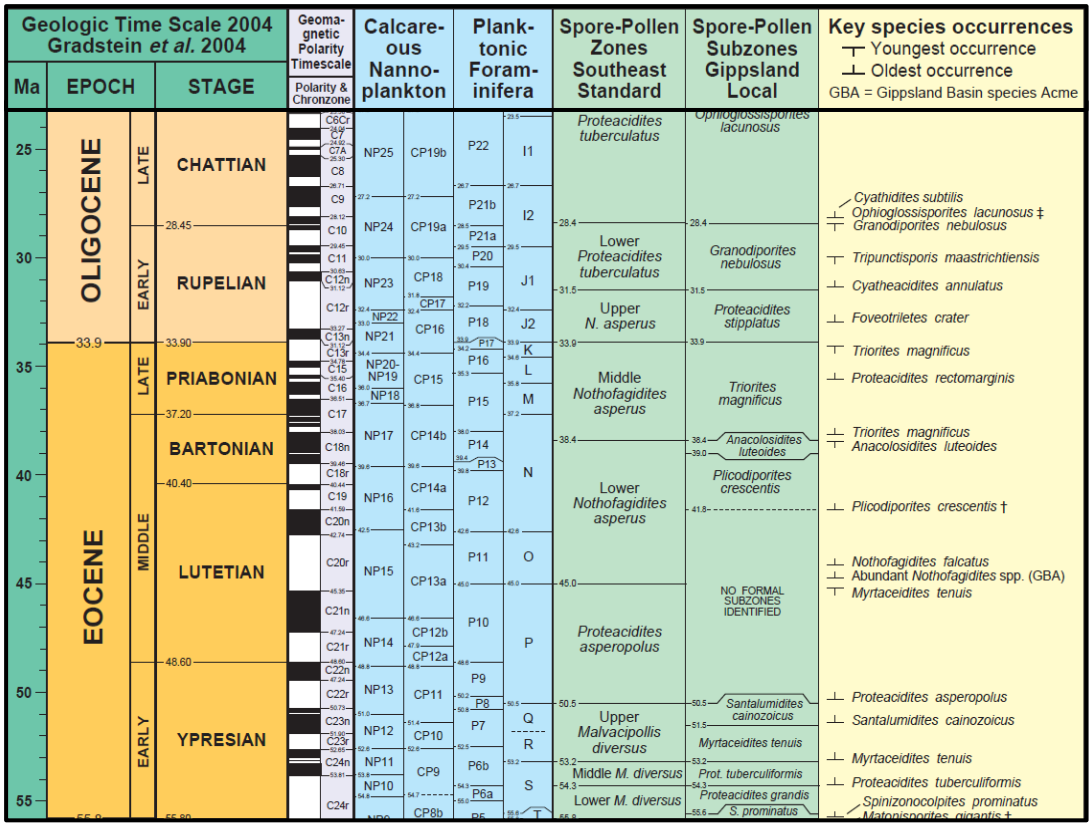


Fig. 3.3 Standard palynozonations for the Eocene and Oligocene of southeast Australia (adapted from Partridge 2006)

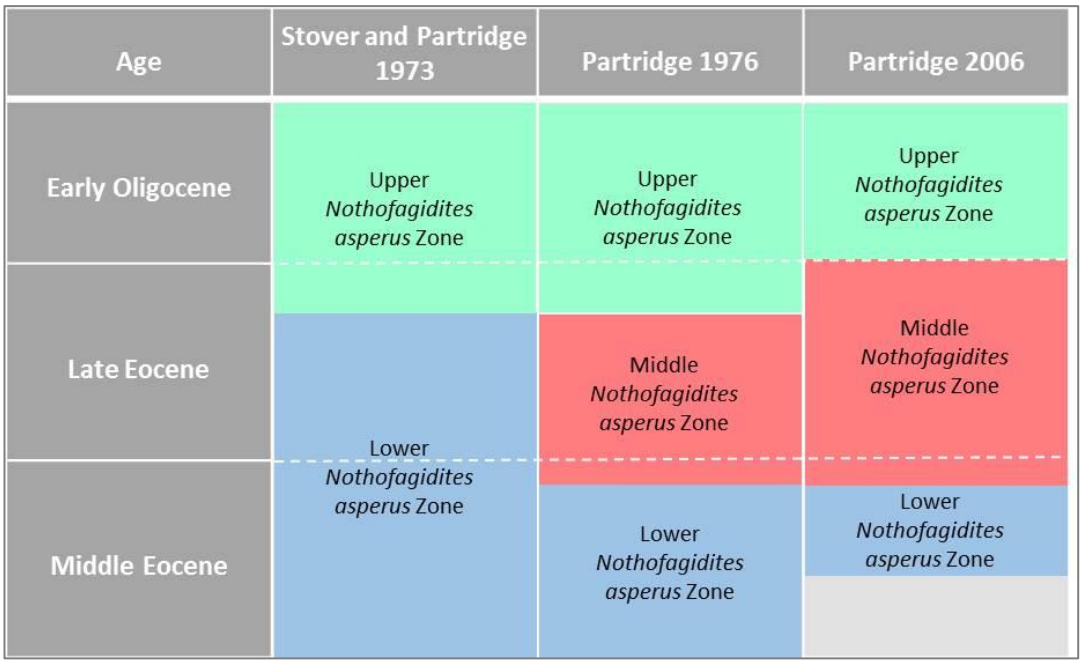


Fig. 3.4 Changes Partridge (2006) made to the age assignment of pre-2006 palynozonation scheme for the southeastern Australian Gippsland Basin.

The Zanthus assemblage from the western margin of the Eucla Basin in Western Australia studied by Milne (1988), appeared to correlate with the lower sections of the *Sparganiaceaepollenites barungensis* zone of Harris (1971) and the equivalent Upper *Nothofagidites asperus* Zone of Stover and Partridge (1973). The palynoflora did not correlate easily however, as the diversity and abundance of proteaceous species in the Zanthus assemblage is atypical of these zones. Similarly, a mid-Eocene palynoflora from St Vincent Basin, South Australia, contained specimens of *Proteacidites confragosus* (Harris 1972) not known from the southeast until the late Miocene (Stover and Partridge 1973, Milne 1988). Zonal fossils may also be entirely absent within palynofloras, as in the early Cenozoic Eyre Formation at Nelly Creek in the southern Lake Eyre Basin (Alley *et al*. 1996). *Nothofagidites asperus* is unrecognised from these sediments though the appearance of the species was taken to mark the base of the Lower *N. asperus* Zone constructed by Stover and Partridge (1973), for the Gippsland Basin.

3.7 Summary

Extensive palynological and palaeobotanical studies of Cenozoic sediments have been carried out in southeastern Australia. From these, standard palynostratigraphic zonations from the Cretaceous to Pliocene have been constructed, and the

palaeovegetation of each epoch well assessed and widely accepted. This has been brought about by the presence of thick successions of sediments spanning the Cenozoic, and substantial funding from companies exploring for petroleum and water.

By contrast, similar Cenozoic studies in southern WA are rare despite the occurrence of many terrestrial sites with sediments containing well-preserved plant material. This is in part due to the limited vertical and horizontal extent of sediments suitable for palynological and palaeobotanical studies, and to the lack of industry-driven research in these areas. Most suitable WA Cenozoic deposits represent only one period of deposition, and are primarily of Eocene age. For these reasons it has not been possible to construct a spore-pollen palynostratigraphic zonation scheme for the Cenozoic of WA.

The use of south-eastern Australian palynozones to date southern WA palynofloras has caused significant problems due to the differing age ranges of many of the index species for the standard zonations outside of the Otway, Gippsland and Murray basins for which they were erected (e.g. at Zanthus). Amendments to these standard zonations (Partridge 1976, Partridge 2006) have not commonly been applied to WA studies, with many publications using Stover and Partridge (1973). This has led to similar aged assemblages in WA being dated as different ages.

Interpretations of the middle to late Eocene palaeovegetation of WA have often deferred to the *Nothofagus*-dominated mesothermal forest interpreted by eastern Australian workers to be present across the entire southern half of the continent at this time (Macphail *et al.* 1994). Several WA studies (e.g. Hos 197; Milne 1988, 1998; Mack and Milne 2015) have indicated that the southwestern middle to late Eocene palynofloras were regionally varied (provincialism) and that southeastern species were occurring outside of their age ranges in the Otway, Gippsland and Murray basins (diachronism).

The Officer Basin material, on which this thesis is based, has already shown the presence of a sclerophyllous component to the palynoflora, similar to that at Zanthus (Mack 2011). Further work on this site is significant, as little work has been

completed in the Officer Basin, and the Mulga Rock deposits contain a rich palynoflora. It is also of importance in that the lithostratigraphy at the site is still informally known, with limited age dating completed.

4. Materials and methods

4.1 Collection of sediment samples

A total of 75 sediment samples were collected from air core and diamond drilling programs undertaken at Mulga Rocks during 2009 and 2012 by Energy and Minerals Australia (EMA), now known as Vimy Resources, and from a 1979 to 1986 PNC Australia Exploration Pty Ltd (PNC) drilling program. Sampling was focused on drill holes in a cross section through the Princess and Ambassador uranium deposits (Fig. 4.1).

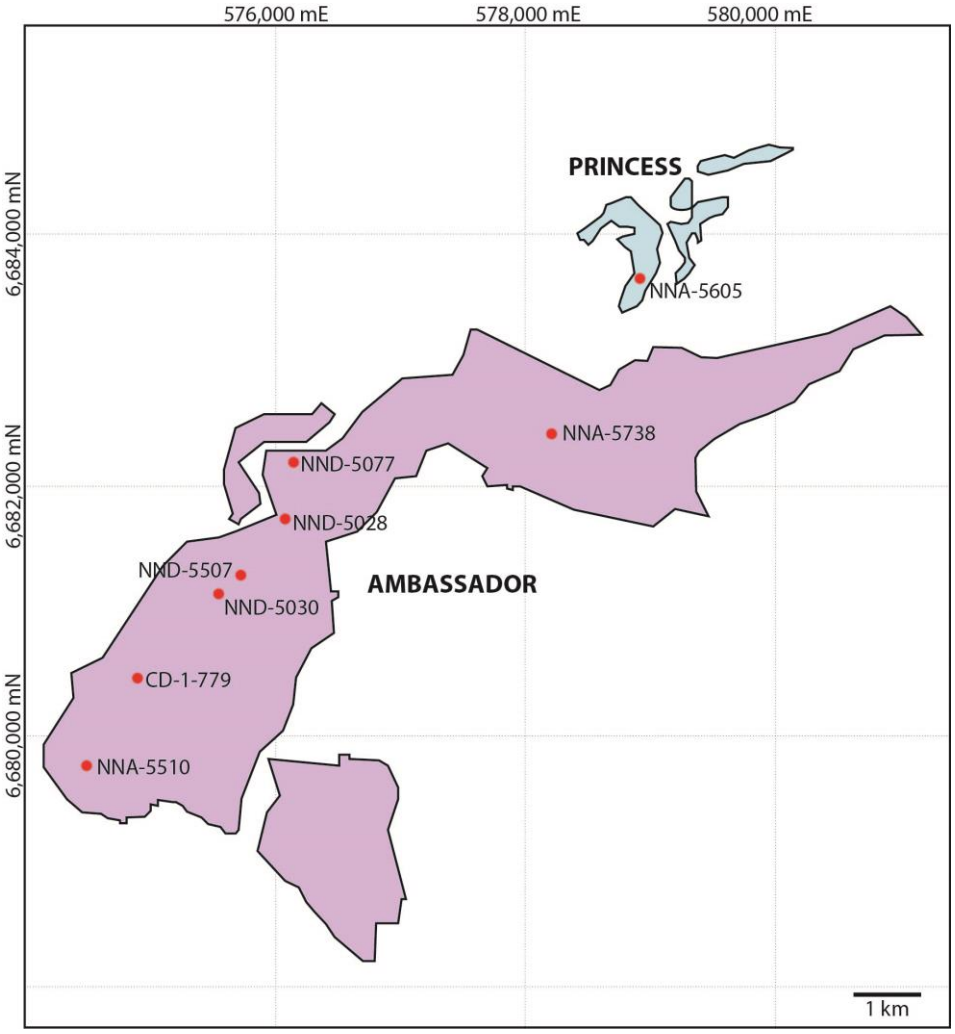


Fig. 4.1 Location of sampled drill holes.

Initial sampling was undertaken in May 2012 at the Mulga Rocks exploration camp. Samples were taken from EMA reference material (late 2011 to early 2012 program) and recovered from PNC drill holes in the field. PNC material stored with the

Department of Mines and Petroleum and donated to Dr Lynne Milne in 1999 was also sampled. Further sediment sample collection was undertaken in September 2013 (2009 and 2011/2012 EMA drilling).

Intervals for collection were selected based on lithology, with lignites, carbonaceous clays and sands preferred. For each sample approximately 20-40 g of sediment was collected and transferred to ziplock bags for transport to Environmental Inorganic Geochemistry Group (EIGG) laboratory facilities. Additional material was collected if the interval had a particularly high sand content, due to a lower percentage of pollen associated with lithologies of this type.

When drilling through the ore bodies (Princess and Ambassador), air core material was collected by EMA into reference bags at 0.1–0.5 m intervals. Samples for palynological analysis in this case were collected at every half metre to one metre. Outside of the ore bodies, one to two metres of air core had often been amalgamated into reference bags. One sample from each of these was collected for analysis. At least one sample per half metre was collected from the EMA diamond core, with finer sampling based on lithological changes.

During PNC drilling, air core was collected into one metre intervals at the drill sites and buried upon completion of the program. One sample from each metre exhumed was collected. As these holes were drilled a significant time ago, outside layers of these samples were removed and only the material that had not been exposed was processed. All of the PNC diamond core held by Dr Lynne Milne was sampled.

All samples are catalogued with depths, lithology and the details of the drill holes from which they were obtained in Appendix 1.

4.2 Sample preparation

All sample preparation was undertaken in a dedicated HF laboratory at Curtin University Building 610 in Technology Park, Bentley. These facilities were operated by EIGG until 2014, and Fuels and Energy Technological Institute (FETI) from 2014

to present. Equipment required was provided by Dr Lynne Milne and EIGG. Chemicals and consumables were purchased with funding from EMA/Vimy Resources. Preparation numbers and sample details are listed in Appendix 2.

4.2.1 Sediment processing

Palynological processing of sediments removes the non-pollen component of sediment to leave a concentrated fraction of organic matter (Phipps and Playford, 1984). Several chemical processes are used that progressively remove minerals and extraneous organic material. The amount of sediment used in palynological processing depends on the proportion of organic material within the rock, with 5 to 10 g optimal for carbonaceous shales and siltstones and coals, and 25-30 g for calcareous or siliceous shales and siltstones, and argillaceous limestones and sandstones.

After cleaning and crushing, the samples were processed according to a modified version of the palynological procedure of Phipps and Playford (1984) and outlined in detail below and in Table 4.1. Chemical amounts listed below are approximate and more was used if the process was deemed incomplete. After each chemical treatment, samples were placed in 50 mL centrifuge tubes and centrifuged for three minutes at 3,000 rpm. After centrifugation the supernatant was discarded and the sample rinsed/centrifuged in distilled water. This rinsing process was repeated three times with the supernatant discarded after each centrifugation.

Carbonate removal: 100 mL of 50% hydrochloric acid (HCl) was added to the sample in a 250 mL glass beaker and heated to approximately 100°C whilst stirring. The resulting liquid was then poured into a 50 mL centrifuge tube and centrifuged to concentrate the solids.

Fluoride removal: The sample was returned to a 250 mL beaker and 100-200 mL of HCl (50%) was added and heated (100°C) until no lumps of fluorosilicates were visible. As the solubility of fluorosilicates increases with temperature, the rinse step was carried out with hot distilled water.

Table 4.1. Chemical treatments used during processing of sediment and extant pollen samples.

Chemical Treatment	Purpose
Sediment Processing	
Hydrochloric acid (HCl)	Removal of calcium and magnesium carbonate minerals
Hydrofluoric acid (HF)	Digestion of silicate minerals
Hydrochloric acid (HCl)	Dissolution of fluorosilicates produced by HF step
Nitric acid (HNO_3)	Removal of non-pollen organic fraction; transforms extraneous organic matter into alkali-soluble humic acids
Sodium hydroxide (NaOH)	Neutralises humic acids produced in nitric acid step
Dilute hydrochloric acid (HCl)	Returns sample to acid environment, as alkali from previous step will destroy palynomorphs over time
Extant Pollen Processing	
Acetolysis (1:9 sulphuric acid (H_2SO_4) & acetic anhydride [$(CH_3CO)_2O$]	Dissolves cellulose and removes protoplasm
Glacial acetic acid (CH_3COOH), prior to acetolysis	Dehydrates samples in water prior to acetolysis
Glacial acetic acid (CH_3COOH), after acetolysis	Removal of hydrophobic acetolysis mixture prior to rehydration of samples in water
NaOH	Lightens pollen grains, removes excess humic and fine organic material
Dilute (HCl)	Returns sample to acid environment, as alkali from previous step will destroy palynomorphs over time

Silicate removal: About 10-15 mL of cold, concentrated (48%) hydrofluoric acid (HF) was added to the sample in the 50 mL tube and then tipped into a 250 mL screw top polypropylene container. The container was placed on a mechanical shaker for 48 hours.

Oxidation (care must be taken at this stage as the palynomorphs are oxidisable): Small quantities (10–20 mL) of nitric acid (HNO_3) were added to the residue in the 50 mL tubes. The resulting solution was then poured into a 250 mL glass beaker and gently heated for 1 to 2 minutes with constant swirling. The reaction was halted by the addition of distilled water.

Alkali treatment: Approximately 15 mL of 5% NaOH was added to each centrifuge tube and the tube shaken to ensure dissolution.

Return to acid/neutral environment: Several pipetted drops of HCl were added to the residue in 15 mL of water to return the residue to an acid environment. The sample was then rinsed/centrifuged several times to bring it back to a neutral environment.

Sieving: The residue was sieved through 100-120 µm nylon mesh to separate pollen grains from larger extraneous material. The sieved liquid was retained and returned to the centrifuge tubes. Where sample size was reduced significantly, the sieving step was skipped in favour of retaining as much material as possible for study. In these cases, the sample was moved to a 15 mL centrifuge tube to further concentrate the fraction.

4.3 Collection of extant pollen

Extant pollen was collected from specimen sheets held at the Perth Herbarium. Where possible, five to eight anthers at the point of dehiscing were collected from up to six different sheets. An additional one to two less mature anthers were collected for comparative purposes. Anthers were dissected with a clean scalpel, under a binocular dissecting microscope to release pollen and remove unwanted debris. Each sample was stored in a clean paper 'wrap' and placed inside labelled envelopes.

4.4 Extant pollen processing

Extant pollen samples were taken directly from herbarium sheets, so only acetolysis of the samples was required (Table 4.1). The technique followed that of Erdtman (1960). Pollen samples were transferred from paper wraps to labelled 15 mL centrifuge tubes and acetolysed. Approximately 5 mL of acetolysis mixture (1:9 mix of concentrated sulphuric acid (H_2SO_4) and acetic anhydride [$(CH_3CO)_2O$] was prepared for each sample and added to the centrifuge tubes. The tubes were heated in hot water (80–100°C) baths for approximately six minutes and shaken vigorously at several intervals. The samples were then rinsed/centrifuged three times in glacial

acetic acid (CH_3COOH) to remove all of the acetolysis mixture prior to rinsing/centrifuging with distilled water.

At this stage, a drop of residue in water was mounted on a microscope slide and examined with a light microscope to check if all of the protoplasm had been removed from the pollen grains. If some remained, the sample was again acetolysed. These samples were dehydrated with three rinses of glacial acetic acid prior to acetolysis.

Those samples in which pollen appeared too dark under light microscopy underwent alkali treatment. Approximately 5 mL NaOH (10%) was added to each tube before it was placed in a hot water (80–100°C) bath for three minutes. Samples requiring alkali treatment also required the addition of a small amount of HCl to the supernatant after rinsing to return the residue to an acidic environment. All samples were sieved with 120 µm nylon mesh to remove larger extraneous organic material.

4.5 Light microscope slide preparation

Residues (organic matter from sediment and extant pollen preparations) were again rinsed with distilled water before a small amount was pipetted into a weak PVC glue solution (approximately 5%) on a glass coverslip and left to dry on a warm hotplate. Once dry, the cover slip was inverted onto a small amount of 'Eukitt' on a glass microscope slide. Care was taken to ensure that the 'Eukitt' spread to the edges of the cover slip before the slide was left to air dry for at least two days. Two slides were prepared for each sample.

4.6 Preparation of pollen for scanning electron microscopy (SEM)

Ethanol (99.8%) was added to the residues from processing of sediment and extant samples (acetolysis) in successive stages to completely dehydrate the pollen grains for scanning electron microscopy. Approximately 4 mL of ethanol was added to 4 mL of sample in water to make up a 50% ethanol solution and the tube vigorously shaken and inverted to mix. The addition of 4 mL was repeated to successively make

up 75% and close to 100% solutions. After centrifuging, samples were rinsed/centrifuged with 100% ethanol three times.

To prepare stubs, one drop of dehydrated residue was placed onto a thermoplastic ('Thermanox') cover slip. The pollen grains formed a cationic bond with the cover slip with no need for additional adhesive. Cover slips were secured to aluminium SEM stubs with double sided carbon tape and the stub placed in a desiccator for at least 30 minutes (often overnight) prior to coating with platinum. Carbon paint was applied to ensure contact of the cover slip with the aluminium stub.

4.7 Analysis

Palynomorph identification and counts were undertaken on an OLYMPUS – BX51 transmitted light biological microscope. For each sample, a count of at least 200 specimens was made. A scan of the remainder of the slide was completed to determine the presence of species outside of counts. This scan was split between the two slides produced to account for variable distribution when pipetting material onto cover slips. All fossil species identified, and their occurrences, are documented in Chapters 5 and 6 and Appendix 3.

For modern *Banksia* pollen a total of 30 grains per species, comprising ten grains from three specimens, were analysed to obtain representative data as outlined in Wrońska-Pilarek *et al.* (2015). Similar data were acquired from two fossil species, except where 30 grains were not available, in which case all available grains were measured. Sculptural detail was determined with scanning electron microscopy of three to four grains.

4.8 Photomicrography

Light photomicrographs were taken on an Olympus – DP71 camera. Scanning electron photomicrographs were taken with the TESCAN Mira 3 in the Microscopy and Microanalysis Facility of Curtin's John de Laeter Centre.

4.9 Repository

All slides and residues from this study are stored with the Geological Survey of Western Australia. Catalogue numbers for illustrated specimens are listed in Appendices 4 and 5. Sediment samples are stored with Vimy Resources.

5. Systematics of previously described species

In this chapter, 163 species of previously described spores and pollen, both gymnosperm and angiosperm, are listed. Where possible, an age range has been given from major Australian biostratigraphic zonation schemes. In other cases, a range has been determined from more localised works in southern Australia though many of these studies aligned spore-pollen assemblages with the standard zonation schemes of Stover and Partridge (1973) which has since been amended. Some species are only currently known from New Zealand, and their distribution there is given. An age has also been provided where the species has been documented in Western Australia. Botanical affinities were sourced from Raine *et al.* (2011) where possible and additional references noted where not. Appendix 3 tabulates the distribution of pollen species within the samples studied. Each species is illustrated in Plates 1–23, in Appendix 6.

5.1 Cryptogam spores

Genus: *Baculatisporites* Thomson and Pflug 1953

Type species: *Baculatisporites primarius* Thomson and Pflug 1953

Baculatisporites comaumensis Cookson (Potonié) 1956 (Plate 1, Figs A, B)

Dimensions: Equatorial diameter 30 (42) 51 µm (9 specimens)

Remarks: Several specimens of *Baculatisporites comaumensis* in the Mulga Rock palynoflora resemble that figured by Mildenhall (1994), which appears to possess echinae rather than baculae, but is otherwise morphologically the same to other figured specimens. In the few specimens that are baculate, the baculae are closer spaced than in specimens from other sites, but still within the known range.

Age range: Baculatisporites comaumensis is a long ranging sporomorph. In south-eastern Australia it ranges from Early Cretaceous in the Murray Basin (Martin 1984a, 1984b), Permian to Early Cretaceous in the Castlereagh River Valley (Martin 1981) and is present in the Eocene Bungonia palynoflora from the Tablelands in NSW (Truswell and Owen 1988). It ranges from late Eocene to early Oligocene in the Pidinga Formation in the eastern Eucla Basin, South Australia (Alley and Benbow 1989). In southern WA, it is of Early Jurassic to

Late Cretaceous age in the Perth Basin (Backhouse 1974) and late Eocene at Zanthus in the western Eucla Basin (Milne 1988).

Botanical affinity: Osmundaceae (royal fern)

Genus: *Cibotiidites* Ross 1949

Type species: *Cibotiidites zonatus* Ross 1949

Cibotiidites tuberculiformis (Cookson 1947) Skarby 1974 (Plate 1, Figs C, D)

Dimensions: 30 µm (1 specimen)

Age range: In south-eastern Australia *Cibotiidites tuberculiformis* ranges from late Palaeocene to late Eocene in the Gippsland Basin (Stover and Partridge 1973); middle Eocene to late Palaeocene in the Otway Basin (Harris 1971); Upper Eocene to early Pliocene in the Murray Basin (Macphail 1999). In south-western Australia, Backhouse (1988) records *C. tuberculiformis* in the Perth Basin, from Late Jurassic to Early Cretaceous. It is not currently known from other WA Paleogene palynofloras.

Botanical affinity: Dicksoniaceae (tree ferns)

Genus: *Cyathidites* Couper 1953

Type species: *Cyathidites australis* Couper 1953

Cyathidites australis* / *minor Couper 1953 (Plate 1, Figs E, F)

Dimensions: Equatorial diameter 19 (30) 59 µm (31 specimens)

Remarks: Traditionally, *Cyathidites australis* has been separated from *C. minor* by size, but the size range in the Mulga Rock palynoflora is continuous and the two are here combined.

Age range: Cyathidites australis/minor ranges from middle Palaeocene to Oligocene in the Otway Basin (Harris 1971) and middle Eocene to Pleistocene in the Murray Basin (Macphail 1999). In south-western Australia it is Early Jurassic to Early Cretaceous in the Perth Basin (Backhouse 1974) and has been noted in the late Eocene Zanthus palynoflora in the western Eucla Basin (Milne 1988).

Botanical affinity: Cyatheaceae (scaly tree ferns)

Genus: *Dictyophyllidites* Couper 1958 emend. Dettman 1963

Type species: *Dictyophyllidites harrisii* Couper 1958

Dictyophyllidites equiexinus (Couper) Dettman 1963 (Plate 1, Fig. G)

Dimensions: Equatorial diameter 74, 76 µm (2 specimens)

Age range: Early Jurassic to Late Jurassic in Western Australia (Backhouse 1988, 1989), and offshore of WA (Burger 1996). Late Jurassic in the Polda Basin on the Eyre Peninsula in South Australia (Harris 1974).

Botanical affinity: Dicksoniaceae (tree ferns)

Genus: *Gleicheniidites* Ross emend. Bolkhovitina 1968

Type species: *Gleicheniidites senonicus* Ross emend. Bolkhovitina 1968

Gleicheniidites circinidites (Cookson) Dettmann 1963 (Plate 1, Fig. H)

Dimensions: Equatorial diameter 22 (31) 42 µm (31 specimens)

Age range: Late Palaeocene to late Eocene in the Otway Basin, Victoria (Harris 1971), Early Cretaceous to Palaeocene in the Murray Basin, NSW (Martin 1979, 1980, and late Eocene in the western Eucla Basin, WA (Zanthus, Milne 1988).

Botanical affinity: Gleicheniaceae (forked ferns)

Genus: *Laevigatosporites* Ibrahim 1933

Type species: *Laevigatosporites vulgaris* Ibrahim 1933

Laevigatosporites ovatus Wilson and Webster 1946 (Plate 1, Figs I–K)

Dimensions: Length 29 (37) 62 µm, width 17 (25) 35 µm (25 specimens)

Remarks: Some specimens retain an outer perforate layer, though the majority are thin walled and psilate.

Age range: Middle Palaeocene to middle Miocene in the Otway Basin, Victoria (Harris 1971). Also recorded from the Late Cretaceous in Victoria (Wagstaff 1989) and present in the Zanthus palynoflora of late Eocene age (Milne 1988).

Botanical affinity: Schizaeaceae (climbing ferns) (Dodson and Macphail 2004)

Genus: *Latrobosporites* Harris 1965

Type species: *Latrobosporites crassus* Harris 1965

Latrobosporites marginis Mildenhall and Pocknall 1989 (Plate 1, Figs L–N)

Dimensions: 24 (31) 37 µm (13 specimens)

Age range: Only recorded from the Murray Basin in Australia, from middle Eocene to early Pliocene (Macphail 1999). Otherwise known from early to middle Miocene in New Zealand (Mildenhall and Pocknall 1989).

Botanical affinity: Lycopodiaceae (club mosses), *Lycopodium laterale*-type

Latrobosporites ohaiensis (Couper) Stover in Stover and Partridge 1973 (Plate 2, Figs A, B)

Dimensions: Equatorial diameter 52 (54) 60 µm (3 specimens)

Age range: Late Cretaceous to middle late Palaeocene in the Gippsland Basin, Victoria (Stover and Partridge 1973, Partridge 2006).

Botanical affinity: Lycopodiaceae (clubmosses)

Genus: *Monolites* Cookson 1947 ex Potonié 1956

Type species: *Monolites major* (Cookson 1947) Potonié 1956

Monolites* cf. *alveolatus Couper 1960 (Plate 2, Figs C, D)

Dimensions: Length 54 µm, width 26 µm (1 specimen)

Remarks: This spore possesses a similar punctate sculpture to that of *Monolites alveolatus*, but is significantly larger than the size range described by Couper (1960).

Age range: Middle Eocene to early Pliocene in the Murray Basin, Victoria (Macphail 1999), early Miocene to late Oligocene in New Zealand (Pocknall and Mildenhall 1984). This is the first record of the species in Western Australia.

Botanical affinity: Polypodiaceae (ferns)

Genus: *Neoraistrickia* Potonié 1956

Type species: *Neoraistrickia truncata* (Cookson) Potonié 1956

Neoraistrickia* cf. *levidensis (Balme) Backhouse 1988 (Plate 2, Figs E, F)

Dimensions: 20, 22 µm (2 specimens)

Remarks: Neoraistrickia cf. *levidensis* closely resembles *N. levidensis* (Balme) Backhouse 1988 but possesses some echinae with wider bases.

Age range: Species of *Neoraistrickia* are mostly known from the Jurassic of Australia (Potonié 1956). Elsewhere in the world the genus ranges from Carboniferous to Pliocene in age.

Botanical affinity: Lycopodiaceae (clubmosses), Selaginellaceae (spike mosses or lesser clubmosses)

Genus: *Peromonolites* Couper 1953

Type species: *Peromonolites densus* Harris 1965

Peromonolites vellosus Partridge in Stover and Partridge 1973 (Plate 2, Figs G, H)

Dimensions: 31, 32 µm long; 20 µm wide (2 specimens)

Age range: Early Palaeocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973), and middle Eocene to early Pliocene in the Murray Basin (Macphail 1999).

Botanical affinity: Filicopsida (ferns)

Genus: *Punctatosporites* Ibrahim 1953

Type species: *Punctatosporites minutus* Ibrahim 1953

Punctatosporites* cf. *scabratus (Couper) Norris 1965 (Plate 2, Figs I, J)

Dimensions: 59 (67) 77 µm long, 32 (35) 41 µm wide (3 specimens)

Remarks: This spore was renamed from *Marattisporites scabratus* (Couper 1958) to *Punctatosporites scabratus* by Norris (1965). It was returned to *Marattisporites* by Backhouse (1988) as the type species of *Punctatosporites* was described with scattered granae, and specimens of *P. scabratus* in the Perth Basin possessed closely spaced granae. Since then, the species name has alternated between *Marattisporites* and *Punctatosporites*, with one assignment to *Polypodiaceaesporites*. Later workers (e.g. Sajjadi and Playford 2002) use *Punctatosporites scabratus* for specimens that more closely resemble those in the Mulga Rock palynoflora, that have a dominantly perforate sculpture and granula infilling the spaces between. *Punctatosporites* cf. *scabratus* most closely resembles the specimen figured by Raine in Landis *et al*. (1999) but is significantly larger than specimens illustrated by Backhouse (1988).

Age range: Specimens of *Marattisporites punctatus* range from Late Jurassic to Early Cretaceous in the Perth Basin of WA (Backhouse 1988). *Punctatosporites scabratus* is known from Queensland, ranging from Late Jurassic to Early Cretaceous in the Eromanga Basin (Burger 1989), and Early Cretaceous in coastal Victoria (Wagstaff 1989).

Botanical affinity: Marattiaceae (giant fern)

Genus: *Rugulatisporites* Thomson and Pflug 1953

Type species: *Rugulatisporites mallatus* Stover in Stover and Partridge 1973

Rugulatisporites micraulaxis Partridge in Stover and Partridge 1973 (Plate 3, Figs E, F)

Dimensions: 29 (38.5) 47 µm (5 specimens)

Age range: Late Miocene in the Gippsland Basin (Stover and Partridge 1973), late Eocene to early Oligocene in the eastern Eucla Basin (Alley and Benbow 1989), and late Eocene in the Zanthus area of the western Eucla Basin, WA (Milne 1988).

Botanical affinity: Thyrsopteridaceae (tree fern) (Macphail 1999 – for other *Rugulatisporites* spp)

Genus: *Verrucatosporites* Thomson and Pflug 1953

Type species: *Verrucatosporites alienus* (Potonié) Thomson and Pflug 1953

Verrucatosporites speciosus Harris 1965 (Plate 2, Figs K, L)

Dimensions: Length 29 (40.5) 61 µm, width 15 (25.5) 32 µm (25 specimens)

Remarks: Specimens of *Verrucatosporites speciosus* in the Mulga Rock palynoflora extend the size range given by Harris (1965). It is possible that more than one species is represented, but no distinct break in the size range is apparent, nor are any readily distinguishable differences in morphology. .

Age range: Late Palaeocene in the Otway Basin (Harris 1971), Palaeocene in Princetown, Victoria (Harris 1965), and late Eocene to early Oligocene in the eastern Eucla Basin (Alley 1989). There is no published record of the species in Western Australia.

Botanical affinity: Filocopsida

Genus: *Verrucosisporites* Ibrahim emend. Smith 1971

Type species: *Verrucosisporites microverrucosus* Ibrahim 1933

Verrucosisporites cristatus Stover and Partridge 1973 (Plate 3, Figs A, B)

Dimensions: Equatorial diameter 54, 75 µm (2 specimens)

Age range: Late Eocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006), late Eocene through early Pliocene in the Murray Basin (Macphail 1999) and late Eocene at Zanthus (Milne 1988).

Botanical affinity: Schizaeaceae, *Lygodium* (climbing ferns)

Verrucosisporites kopukuensis (Couper 1960) Stover in Stover and Partridge 1973 (Plate 3, Figure C, D)

Dimensions: Equatorial diameter 43 (61) 70 µm (9 specimens)

Remarks: Specimens of *Verrucosisporites kopukuensis* in the Mulga Rock palynoflora show variability in the distribution of verrucae, though all forms remain within the continuum described by Stover and Partridge (1973).

Age range: Early Eocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006), middle Eocene to early Pliocene in the Murray Basin (Macphail 1999) and middle to late Eocene in the Otway Basin (Harris 1971). Present in the middle to late Eocene Werillup Formation in Western Australia (Stover and Partridge 1982).

Botanical affinity: Schizaeaceae, *Lygodium articulatum*-type (climbing ferns)

5.2 Gymnosperm pollen

5.2.1 Bisaccate pollen

Genus: *Lygistepollenites* Stover and Evans 1973

Type species: *Lygistepollenites balmei* (Cookson) Stover and Evans 1973

Lygistepollenites florinii (Cookson and Pike) Stover and Evans 1973 (Plate 3, Figs G, H and Plate 4, Figs A, B)

Dimensions: Whole grain diameter 20 (30) 40 µm, corpus diameter 24 (39) 56 µm (25 specimens)

Age range: Palaeocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006), middle Eocene to early Pliocene in the Murray Basin (Macphail 1999). Present in the late Eocene Zanthus palynoflora (Milne 1988) and in the middle to late Werillup Formation (Stover and Partridge 1982).

Botanical affinity: Podocarpaceae, *Dacrydium* (conifers) (Macphail 1999)

Genus: *Parvisaccites* Couper 1958

Type species: *Parvisaccites radiatus* Couper 1958

Parvisaccites catastus Partridge in Stover and Partridge 1973 (Plate 4, Figs C–F)

Dimensions: Whole grain diameter 18 (25) 35 µm, corpus diameter 24 (32) 45 µm (20 specimens)

Age range: Late Palaeocene to middle Oligocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006), late Eocene to early Pliocene in the Murray Basin (Macphail 1999), and late Eocene to early Oligocene in the eastern Eucla Basin (Alley and Benbow 1989). Not yet recorded from southern WA.

Botancial affinity: Podocarpaceae, *Dacrydium bidwillii*-type (conifers) (Macphail 1999)

Genus: *Phyllocladidites* Cookson ex Couper emend. Stover and Evans 1973

Type species: *Phyllocladidites mawsonii* Cookson ex Couper 1953

Phyllocladidites mawsonii Cookson 1947 ex Couper 1953 (Plate 4, Figs G–J)

Dimensions: Whole grain diameter 30 (36) 51 µm, corpus diameter 21 (24) 35 µm (30 specimens)

Remarks: Most specimens of *Phyllocladidites mawsonii* in the Mulga Rock palynoflora have infolded sacci, thus the corpus measurements are for 30 grains. The whole grain measurement reflects those where the sacci extended past the corpus, which only occurred in nine of the grains measured.

Age range: Late Cretaceous to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006). Palaeocene to middle Miocene in the Otway Basin (Harris 1971), and Palaeocene to early Pliocene in the Murray Basin (Macphail 1999). In south-western Australia *Phyllocladidites mawsonii* is present in the middle to late Eocene Werillup Formation (Stover and Partridge 1982) and late Eocene sediments at Zanthus (Milne 1988).

Botanical affinity: Podocarpaceae, *Lagarostrobos franklinii*-type (conifer, commonly known as Huon or Macquarie pine) (Macphail 1999)

Genus: *Podocarpidites* Cookson 1947

Type species: *Podocarpidites ellipticus* Cookson ex Couper 1953

Podocarpidites ellipticus Cookson 1947 ex Couper 1953 (Plate 4, Figs K–M)

Dimensions: Whole grain diameter 22 (30.5) 45 µm, corpus diameter 32 (45) 54 µm (28 specimens)

Age range: Middle Palaeocene to late Eocene in the Otway Basin (Harris 1971). Present in late Eocene to early Oligocene palaeochannel sediments at Coolgardie, WA (Balme 1959). Also recorded in WA from the late Eocene Zanthus palynoflora (Milne 1988).

Botanical affinity: Podocarpaceae, similar to *Podocarpus* and *Dacrydium* (conifers) (Dettmann and Jarzen 1990)

Podocarpidites puteus Mildenhall and Pocknall 1989 (Plate 4, Figs N, O)

Dimensions: Whole grain diameter 14 (20) 21 µm, corpus diameter 23 (25.5) 27 µm (4 specimens)

Age range: Podocarpidites puteus is previously unrecorded from Australia. It is of early to middle Miocene age in New Zealand (Mildenhall and Pocknall 1989).

Botanical affinity: Podocarpaceae, *Podocarpus* (conifer)

5.2.2 Trisaccate pollen

Genus: *Dacrycarpites* Cookson and Pike 1953

Type species: *Dacrycarpites australiensis* Cookson and Pike 1953

Dacrycarpites australiensis Cookson and Pike 1953 (Plate 4, Figs P, Q)

Dimensions: Whole grain diameter 24 (30) 45 µm, corpus diameter 35 (36.5) 51 µm (20 specimens)

Age range: Late Palaeocene to middle Miocene in the Otway Basin (Harris 1971) and middle Eocene to Pleistocene in the Murray Basin (Macphail 1999). In Western

Australia it is recorded from the late Eocene Zanthus palynoflora (Milne 1988) and in late Eocene to early Oligocene sediments at Coolgardie (Balme and Churchill 1959).

Botanical affinity: Podocarpaceae, *Dacrycarpus dacrydioides* (kahikatea, coniferous tree in New Zealand)

Genus: *Trichotomosulcites* Couper 1953

Type species: *Trichotomosulcites subgranulatus* Couper 1953

Trichotomosulcites subgranulatus Couper 1953 (Plate 4, Figs R, S)

Dimensions: Equatorial diameter 17 (23) 33 µm (23 specimens)

Age range: Late Eocene to early Pliocene in the Murray Basin (Macphail 1999). Present in the late Eocene to early Oligocene Pidinga Formation in the eastern Eucla Basin (Alley and Benbow 1989). Also recorded from the late Eocene Zanthus palynoflora (Milne 1988).

Botanical affinity: Podocarpaceae, extinct *Microcachrys* (conifer)

5.3 Angiosperm pollen

5.3.1 Monocolpate, monoporate and monosulcate pollen

Genus: Aglaoreidia Erdtman 1960

Type species: *Aglaoreidia cyclops* Erdtman 1960

Aglaoreidia qualumis Partridge in Stover and Partridge 1973 (Plate 5, Figs A, B)

Dimensions: Equatorial diameter 27 (27) 30 µm (3 specimens)

Age range: Late Eocene to early Oligocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006). Late Eocene to middle Miocene in the Murray Basin (Macphail 1999).

Botanical affinity: Sparganiaceae (Dodson and Macphail 2004)

Genus: *Arecipites* Wodehouse emend. Anderson 1960

Type species: *Arecipites punctatus* (Wodehouse 1933) Potonié 1958

Arecipites subverrucatus (Pocknall) Mildenhall and Pocknall 1989 (Plate 5, Figs E, F)

Dimensions: Long equatorial axis 41 µm, short equatorial axis 23 µm (1 specimen)

Age range: Previously unrecorded in Australia. Oligocene in New Zealand (Mildenhall and Pocknall 1989).

Botanical affinity: Arecaceae (palm trees)

***Arecipites waitakiensis* (**McIntyre 1968) Mildenhall and Pocknall 1989 (Plate 5, Figs G–I)

Dimensions: Long equatorial axis 32 (36) 50 µm, short equatorial axis 14 (19) 29 µm (3 specimens)

Age range: Middle Oligocene to early Miocene in the Murray Basin (Truswell *et al.* 1985) and late Eocene in the western Eucla Basin (Milne 1988). *Arecipites waitakiensis* is of Miocene age in New Zealand (Mildenhall and Pocknall 1989).

Botanical affinity: Arecaceae (palm trees)

Genus: *Clavatipollenites* Couper 1958

Type species: *Clavatipollenites hughesii* Couper 1958 emend. Kemp 1968

Clavatipollenites ascarinoides McIntyre 1968 (Plate 5, Figs C, D)

Clavatipollenites glarius Stover and Partridge 1973, Plate 20, Figs 8, 9

Dimensions: Long equatorial axis 16 (27) 32 µm, short equatorial axis 10 (19) 22 µm (15 specimens)

Remarks: Stover and Partridge (1982) described *Clavatipollenites glarius* with illustrations that bear a strong resemblance to *C. ascarinoides*. The descriptions differ slightly, with McIntyre describing the sexine to be composed of clavae, with Stover and Partridge (1982) referring to pilae. However, the grains illustrated by Stover and Partridge (1982) appear to be clavate. It should also be noted that both species were aligned with modern *Ascarina.*

Age range: Clavatipollenites ascarinoides was documented from the Werillup Formation by Hos (1975), but is otherwise known from the Cretaceous to Neogene in New Zealand (Raine *et al.* 2011). *Clavatipollenites glarius* was described from the

middle to late Eocene Werillup Formation (Stover and Partridge 1982) and is upper Eocene to early Pliocene in the Murray Basin (Macphail 1999).

Botanical affinity: Chloranthaceae, *Ascarina*

Genus: *Liliacidites* Couper 1953

Type species: *Liliacidites kaitangataensis* Couper 1953

Liliacidites aviemorensis McIntyre 1968 (Plate 5, Figs J–L)

Dimensions: Long equatorial axis 19 (27) 35 µm, short equatorial axis 10 (19) 24 µm (17 specimens)

Age range: Late Eocene to early Oligocene in the eastern Eucla Basin (Alley and Benbow 1989). Reported from the late Eocene Werillup Formation (Hos 1975) and the Zanthus area (Milne 1988) in WA. Otherwise ranges from late Oligocene to late Miocene in New Zealand (Raine *et al.* 2011).

Botanical affinity: Liliaceae (lily)

Liliacidites variegatus Couper 1953 (Plate 5, Figs M, N)

Dimensions: Long equatorial axis 24 (30) 31 µm, short equatorial axis 16 (22) 24 µm (3 specimens)

Age range: Late Eocene to early Oligocene in the eastern Eucla Basin (Alley and Benbow 1989). Present in the late Eocene Werillup Formation (Hos 1975). Cretaceous to Neogene in New Zealand (Raine *et al.* 2011).

Botanical affinity: Liliaceae (lily)

Genus: *Sparganiaceaepollenites* Thiergart 1937 ex Potonié 1960

Type species: *Sparganiaceaepollenites polygonalis* Thiergart 1937, by subsequent designation of Potonié (1937)

Sparganiaceaepollenites barungensis Harris 1972 (Plate 5, Figs O–Q)

Dimensions: Equatorial diameter 19 (20) 22 µm (3 specimens)

Age range: Middle Eocene to early Pliocene in the Murray Basin (Macphail 1999). In Western Australia it occurs in the late Eocene Zanthus palynoassemblage (Milne 1988).

Botanical affinity: Sparganiaceae

5.3.2 Tricolpate pollen

Genus: *Perfotricolpites* Guzman 1967

Type species: *Perfotricolpites digitatus* Guzman 1967

Perfotricolpites digitatus Guzman 1967 (Plate 5, Figs T –V)

Dimensions: Equatorial diameter 45 µm (1 specimen)

Remarks: Germeraad *et al.* 1967 compared *Perfotricolpites digitatus* to *Merremia* of the Convulvulaceae family. Pocknall (1982) describes an undoubted affinity to the family and likened it to pollen produced by the genus *Convolvulus.* Extant species of the family are widespread across Western Australia and occur in numerous environments, with their distribution extending into the arid zone.

Age range: Late Eocene to late Pliocene in the Murray Basin (Macphail 1999), though this was *Perfotricolpites* cf. *digitatus;* late Eocene to Oligocene in Queensland (Dettmann 2000). Also known from the late Oligocene (Pocknall 1982) and the middle Pliocene (Mildenhall 1980) of New Zealand.

Botanical affinity: Convulvulaceae, *Convulvus* (bindweed or morning glory) (Pocknall 1982)

Genus: *Tricolpites* Cookson ex Couper 1953

Type species: *Tricolpites reticulatus* Cookson ex Couper 1953

Tricolpites confessus Stover in Stover and Partridge 1973 (Plate 5, Figs R –S)

Dimensions: Equatorial diameter 11 (15) 17 µm (9 specimens)

Age range: Late Cretaceous in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006).

Botanical affinity: Dicotyledonae

Tricolpites incisus Stover in Stover and Partridge 1973 (Plate 5, Figs W –BB)

Dimensions: Equatorial view 19 (24) 16 µm long, 13 (19) 23 µm wide (15 specimens); polar diameter 17 (23) 30 (40 specimens)

Age range: Early to late middle Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); middle to late Eocene in the Murray Basin (Macphail 1999).

Botanical affinity: unidentified angiosperm

Tricolpites* cf. *lilliei Couper 1953 (Plate 6, Figs A, B)

Dimensions: Equatorial diameter 22 µm (1 specimen)

Remarks: Tricolpites cf. *lilliei* in the Mulga Rock assemblage differs from specimens described by Couper (1953) in that it is smaller in size, and possesses a thinner exine with more closely spaced granules.

Age range: Late Cretaceous in the Gippsland Basin (Stover and Evans 1973). Present in the late Eocene Werillup Formation in southern WA (Hos 1975).

Botanical affinity: Dicotyledonae

Tricolpites perlongicolpus Pocknall and Mildenhall 1984 (Plate 6, Figs C –E)

Dimensions: 25, 30 long, 15 (17) 20 wide (3 specimens)

Age range: Early Oligocene to late Eocene in the eastern Eucla Basin (Alley and Benbow 1989). Otherwise known from the Palaeogene to Neogene of New Zealand (Raine *et al.* 2011).

Botanical affinity: Dicotyledonae

Tricolpites phillipsii Stover in Stover and Partridge 1973 (Plate 6, Fig. F)

Dimensions: Equatorial diameter 25 µm (1 specimen)

Remarks: The sole specimen of *Tricolpites phillipsii* observed in this study was heavily corroded.

Age range: Palaeocene to late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and middle to late Eocene in the Murray Basin (Macphail 1999). Milne (1988) documented *T. phillipsii* in the late Eocene Zanthus palynoassemblage.

Botanical affinity: Dicotyledonae

Tricolpites* cf. *reticulatus Cookson ex Couper 1953 (Plate 6, Figs G, H)

Dimensions: Polar diameter 21, 23 µm (2 specimens)

Remarks: Tricolpites cf. *reticulatus* differs from *T. reticulatus* in that the amb is circular, rather trilobate.

Botanical affinity: Dicotyledonae. *Tricolpites reticulatus* is aligned with Gunneraceae (*Gunnera)* but this affinity is uncertain for this species as it is only compared with *T. reticulatus*.

Tricolpites secarius McIntyre 1965 (Plate 6, Figs I –K)

Dimensions: Polar diameter 22 (23.5) 25 µm (6 specimens)

Age range: Tricolpites secarius has not previously been recorded in Australia. It is known from the Palaeogene in New Zealand (Raine *et al.* 2011).

Botanical affinity: Dicotyledonae

Tricolpites simatus Partridge in Stover and Partridge 1973 (Plate 6, Figs L –N)

Dimensions: Polar diameter 17 (20) 25 µm (12 specimens)

Age range: Middle to late Eocene in the Gippsland Basin, Victoria (Stover and Partridge 1973, Partridge 2006), and middle Eocene to middle Miocene in the Murray Basin (Macphail 1999). In southern Western Australia, it is recorded from the late Eocene Zanthus palynoflora (Milne 1988).

Botanical affinity: Santalales, Loranthaceae (Macphail 1999)

Tricolpites thomasii **(syncolpate)** Cookson and Pike 1954 (Plate 6, Figs Q, R)

Dimensions: Polar diameter 12 (16) 18 µm (16 specimens)

Remarks: Most specimens of *Tricolpites thomasii* in the Mulga Rock palynoflora have colpi extending to the poles, and are syncolpate rather than tricolpate.

Age range: Middle through late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006). Upper Eocene in the Murray Basin (Macphail 1999) and late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: Loranthaceae? (Macphail 1999)

Tricolpites **cf.** ***thomasii*** Cookson and Pike 1954 (Plate 6, Figs O, P)

Dimensions: Polar diameter 20 (22) 24 µm (3 specimens)

Remarks: Tricolpites cf. *thomasii* differs from *T. thomasii* in that it lacks the mesocolpial thickening of the exine and possesses a finer mesoporial reticulum.

Botanical affinity: uncertain, though may be similar to *T. thomasii*

5.3.3 Tricolporate pollen

Genus: *Ailanthipites* Wodehouse 1933

Type species: *Ailanthipites berryi* Wodehouse 1933

Ailanthipites mulleri (Kemp) Milne 1988 (Plate 7, Figs A–E)

Dimensions: Polar diameter 22 (28.5) 34 µm, equatorial diameter 14 (17) 27 µm (20 specimens)

Remarks: Specimens of *Ailanthipites mulleri* in the Mulga Rock palynoflora are significantly larger than those from Ninetyeast Ridge described by Kemp and Harris (1977). Milne (1988) described one larger specimen that is still smaller than most observed at Mulga Rock. The sexinal ridges are consistently less than 1 µm wide, contrary to Milne's (1988) suggestion that sexinal ridge width may increase with size.

Age range: Middle Eocene in the Lake Eyre Basin, SA (Alley 1996), Oligocene at the Ninetyeast Ridge, Indian Ocean (Kemp and Harris 1977) and. late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: A similar striate exine occurs in the Leguminosae, Anacardiaceae, Sapindaceae, Cucurbitaceae, Nolanceae, Aceracae, Rosaceae, Simarubaceae and Hippocastanaceae (Milne 1988)

Ailanthipites paenestriatus (Stover in Stover and Partridge 1973) Milne 1988 (Plate 7, Figs F–J)

Dimensions: Polar diameter 19 (23) 31 µm, equatorial diameter 9 (14) 21 µm (46 specimens)

Age range: Palaeocene through late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006). Upper Eocene to lower Pliocene in the Murray Basin (Macphail 1999). In WA, late Eocene at Zanthus (Milne 1988) and middle to late Eocene in the Werillup Formation of the former Bremer Basin (Stover and Partridge 1982), WA.

Botanical affinity: A similar striate exine occurs in the Leguminosae, Anacardiaceae, Sapindaceae, Cucurbitaceae, Nolanceae, Aceracae, Rosaceae, Simarubaceae and Hippocastanaceae (Milne 1988)

Genus: *Ilexpollenites* Thiergart ex Potonié 1960

Type species: *Ilexpollenites iliacus* Thiergart ex Potonié 1960

Ilexpollenites anguloclavatus McIntyre 1968 (Plate 7, Figs N–R)

Dimensions: Equatorial view; Polar diameter 21 (24) 35 µm, equatorial diameter 10 (16) 25 µm (9 specimens); polar view; diameter 18 (23.5) 28 µm (8 specimens)

Remarks: Ilexpollenites anguloclavatus has only been used in this case for those specimens that are distinctly clavate. It has previously been assigned, by other authors (e.g. Macphail 1999, Plate 9, Fig. 21), to grains that can more accurately be described as pilate, and it is suggested that these specimens be moved to *I. megagemmatus* McIntyre (1968).

Age range: Late Cretaceous to early Miocene in the Gippsland Basin (Stover and Partridge 1973), and middle Eocene to middle Miocene in the Murray Basin (Macphail 1999). Present in the middle to late Eocene palynoflora from the Werillup Formation in Western Australia (Stover and Partridge 1982).

Botanical affinity: Aquifoliaceae, *Ilex* (holly)

Ilexpollenites megagemmatus McIntyre 1968 (Plate 7, Figs S, T)

Dimensions: Equatorial view; polar diameter 24 (29) 31 µm, equatorial diameter 16 (19) 24 µm (8 specimens); polar view; diameter 18 (21) 23 µm (6 specimens)

Age range: In Australia, *Ilexpollenites megagemmatus* is only currently known from the eastern Eucla Basin, ranging from late Eocene to early Oligocene in age (Alley 1989). In New Zealand, it is known from the middle Eocene to Miocene (McIntyre 1968).

Botanical affinity: Aquifoliaceae, *Ilex* (holly)

Ilexpollenites verrucatus Pocknall and Mildenhall 1984 (Plate 7, Figs U, V)

Dimensions: Polar diameter 26 (27) 32 µm, equatorial diameter 17, 19 µm (3 specimens)

Age range: Previously unrecorded from Australia. Early Miocene in New Zealand (Pocknall and Mildenhall 1984).

Botanical affinity: Aquifoliaceae, *Ilex* (holly)

Genus: *Rhoipites* Wodehouse 1933

Type species: *Rhoipites bradleyi* Wodehouse 1933

Rhoipites alveolatus (Couper 1953) Pocknall and Crosbie 1982 (Plate 7, Figs W–BB)

Dimensions: Equatorial view; Polar diameter 17 (25) 27 µm, equatorial diameter 14 (18) 23 µm (24 specimens); polar view diameter 20 (23) 29 µm (15 specimens)

Age range: Upper Eocene to early Pliocene in the Murray Basin, NSW (Macphail 1999) and late Eocene at Zanthus in the western Eucla Basin, WA (Milne 1988).

Botanical affinity: Acanthaceae, *Avicennia*? (bear's breeches); Euphorbiaceae *Excoecaria*?; Caesalpiniaceae? (peacock flower family); Verbenaceae? (verbena or vervain family) (Macphail 1999)

Rhoipites angurium (Partridge 1973) Pocknall and Mildenhall 1984 (Plate 7, Figs CC, DD)

Dimensions: Polar diameter 21 (26) 32 µm, equatorial diameter 12 (17) 25 µm (25 specimens)

Age range: Middle through late Eocene in the Gippsland Basin, VIC (Stover and Partridge 1973). Upper Eocene to early Pliocene in the Murray Basin, NSW (Macphail 1999) and late Eocene at Zanthus in the western Eucla Basin (Milne 1988).

Botanical affinity: Dicotyledonae

Rhoipites* cf. *aralioides Pocknall and Mildenhall 1984 (Plate 8, Figs A–D)

Dimensions: Polar diameter 27 (28) 33 µm, equatorial diameter 22, 23 µm (3 specimens)

Remarks: Rhoipites cf. *aralioides* lacks the fusing of collumellae that makes the sexine appear verrucate-vermiculate as in *R. aralioides*. It otherwise is morphologically similar to the description given by Pocknall and Mildenhall (1984), if a little smaller.

Botanical affinity: Rhoipites aralioides has affinities with Dicotyledonae, *Araliaceae* (ivy) and many other families (Raine *et al.* 2011)

Rhoipites cissus Macphail and Truswell 1993 (Plate 8, Figs E–I)

Dimensions: Polar diameter 26 (30.5) 38 µm, equatorial diameter 17 (23) 26 µm (16 specimens)

Age range: Upper Eocene to early Pliocene in the Murray Basin, NSW (Macphail 1999).

Botanical affinity: Vitaceae (*Cissus*-type) (woody vines) (Dodson and Macphail 2004)

Rhoipites fragilis Mildenhall and Pocknall 1989 (Plate 8, Figs J, K)

Dimensions: Polar diameter 23 (27) 28 µm, equatorial diameter 12 (17) 20 µm (7 specimens)

Age range: Previously unrecorded from Australia. Early to middle Miocene in New Zealand (Mildenhall and Pocknall 1989).

Botanical affinity: Dicotyledonae

Rhoipites goulburnensis Truswell and Owen 1988 (Plate 8, Figs O–S)

Dimensions: Polar diameter 18 (26) 31 µm, equatorial diameter 14 (19) 23 µm (23 specimens)

Age range: Described from the middle Eocene Bungonia palynoflora in NSW (Truswell and Owen 1988).

Botanical affinity: Unknown (Truswell and Owen 1988)

Rhoipites hawkdunensis Mildenhall and Pocknall 1989 (Plate 8, Figs L–N)

Dimensions: Polar diameter 16 (19) 22 µm, equatorial diameter 11 (13.5) 15 µm (16 specimens)

Age range: Not previously recorded in Australia. Early to middle Miocene in New Zealand (Mildenhall and Pocknall 1989).

Botanical affinity: Dicotyledonae

Rhoipites ivanhoensis (Martin 1973) Wood 1986 (Plate 8, Figs Z–BB)

Dimensions: Polar diameter 12 (20) 26 µm, equatorial diameter 9 (16) 19 µm (35 specimens)

Age range: Eocene to Oligocene in the Lachlan River Valley (Martin 1973a), and Oligocene to early Miocene in the Murray Basin (Martin 1977).

Botanical affinity: Many dicotyledonous families; e.g. Rutaceae, Rubiaceae, Euphorbiaceae, Araliaceae and Umbelliferae (Martin 1973)

Rhoipites microreticulatus (Harris) Macphail and Truswell 1993 (Plate 8, Figs T–Y)

Dimensions: Polar diameter 19 (26) 33 µm, equatorial diameter 14 (18) 26 µm (19 specimens)

Remarks: Truswell and Macphail (1993) figured *Rhoipites* cf. *microreticulatus*, which was figured again as *R. microreticulatus* (i.e. the same photomicrograph) in Macphail (1999). The specimen figured in these two papers is distinct from that described by Harris (1965). Forms resembling the figures in both Harris (1965) and Macphail (1999) are present in the Mulga Rock palynoflora. However, the brief remarks given in Truswell and Macphail (1993) do not provide enough of a description to assess the combination of these two forms.

Age range: Late Eocene to early Pliocene in the Murray Basin, NSW (Macphail 1999), late Palaeocene in the Otway Basin (Harris 1971), and middle to late Eocene in the Eucla Basin, WA (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Dicotyledonae

Rhoipites minutiformis Truswell and Owen 1988 (Plate 8, Figs CC–FF)

Dimensions: Polar diameter 11 (14) 20 µm, equatorial diameter 6 (10) 17 µm (31 specimens)

Age range: Middle Eocene at Bungonia in NSW (Truswell and Owen 1988).

Botanical affinity: unknown (Truswell and Owen 1988)

Rhoipites muehlenbeckiaformis Macphail and Truswell 1993 (Plate 8, Figs GG–II)

Dimensions: Polar diameter 22 (23) 25 µm, equatorial diameter 19 (20) 21 µm (3 specimens)

Age range: Upper Eocene to lower Pliocene in the Murray Basin, NSW (Macphail 1999).

Botanical affinity: Polygonaceae, *Muehlenbeckia* (maidenhair) (Macphail 1999)

Rhoipites rotundiformis Truswell and Owen 1988 (Plate 8, Figs JJ–KK)

Dimensions: Polar diameter 20 (22) 23 µm, equatorial diameter 19 (20) 23 µm (7 specimens)

Age range: Middle Eocene at Bungonia in NSW (Truswell and Owen 1988). This is the first report of *Rhoipites rotundiformis* outside of Bungonia.

Botanical affinity: unknown (Truswell and Owen 1988)

Rhoipites sphaerica (Cookson) Pocknall and Crosbie 1972 (Plate 9, Fig. T)

Dimensions: Polar diameter 16 (23.5) 31 µm, equatorial diameter 13 (18) 26 µm (26 specimens)

Age range: Late Eocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973). Upper Eocene to early Pliocene in the Murray Basin (Macphail 1999) and late Eocene at Zanthus in Western Australia (Milne 1988).

Botanical affinity: Dicotyledonae

Genus: *Schizocolpus* Stover in Stover and Partridge 1973

Type species: *Schizocolpus marlinensis* Stover in Stover and Partridge 1973

Schizocolpus marlinensis Stover in Stover and Partridge 1973 (Plate 9, Figs A–C)

Dimensions: Equatorial diameter 16 (18) 20 µm (12 specimens)

Age range: Early to middle Eocene in the Gippsland Basin, VIC (Stover and Partridge 1973), upper Eocene to middle Miocene in the Murray Basin (Macphail 1999) and late Eocene at Zanthus in the western Eucla Basin (Milne 1988).*Botanical affinity:* Didymelaceae (Macphail 1999)

Genus: *Tricolporites* Cookson 1947

Type species: *Tricolporites sphaerica* Cookson 1947

***Tricolporites adelaidensis* (**Harris) Stover and Partridge 1982 (Plate 9, Figs D–H)

Dimensions: Equatorial view; polar diameter 25 (33) 48 µm, equatorial diameter 24 (30) 40 µm (13 specimens). Polar view; equatorial diameter 29 (34.5) 48 (22 specimens)

Age range: Middle Eocene to middle Miocene in the Murray Basin (Macphail 1999). In Western Australia it occurs in the middle to late Eocene in the Werillup Formation (Stover and Partridge 1982) and is recorded from the late Eocene palynoflora at Zanthus (Milne 1988).

Botanical affinity: Meliaceae? (mahogany), *Dysoxylum* (Macphail 1999)

Tricolporites* cf. *cooksonii Martin 1973 (Plate 9, Figs I–K)

Dimensions: Polar diameter 31 µm, equatorial diameter 17 µm (1 specimen)

Remarks: Tricolporites cf. *cooksonii* differs from *T. cooksonii* in that it possesses a slightly thicker exine and a coarser reticulum.

Botanical affinity: unidentified angiosperm (Macphail 1999)

Tricolporites leuros Partridge in Stover and Partridge 1973 (Plate 9, Figs L, M)

Dimensions: Equatorial view; polar diameter 18 µm, equatorial diameter 20 µm (1 specimen). Polar view 17 (19) 27 µm (41 specimens)

Remarks: Occasional tetracolporate forms were observed, and only a single specimen in the equatorial view.

Age range: Middle Eocene to late Miocene in the Murray Basin (Macphail 1999), middle Eocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006), and middle to late Eocene in Western Australia (Stover and Partridge 1982, Milne 1988).

Botanical affinity: unidentified angiosperm (Macphail 1999)

Tricolporites prolata Cookson 1947 (Plate 9, Figs P–S)

Dimensions: Polar diameter 15 (23) 31 µm, equatorial diameter 11 (14) 19 µm (33 specimens)

Age range: Palaeocene at Princetown, VIC (Harris 1965) and late Eocene to early Oligocene in the eastern Eucla Basin (Alley 1989), extending to the middle Eocene at One Tree Hill (Alley 1992). In Western Australia, it ranges from late Eocene (Milne 1988) to early Pliocene (Bint 1981).

Botanical affinity: Dicotyledonae

Tricolporites* cf. *prolata Cookson 1947 (not illustrated)

Dimensions: Polar diameter 24 µm, equatorial diameter 13 µm (1 specimen)

Remarks: Tricolporites cf. *prolata* differs from *Tricolporites prolata* Cookson 1947 in that the sexine is perforate, with perforations approximately 0.5 µm in diameter.

Tricolporites scabratus Harris 1965 (Plate 9, Figs U, V)

Dimensions: Equatorial view; polar diameter 34 (38) 42 µm, equatorial diameter 22 (29) 34 µm (21 specimens). Polar view, diameter 31 (39.5) 43 µm (8 specimens)

Age range: Early to late Eocene in the Gippsland Basin (Stover and Partridge 1973), upper Eocene to middle Miocene in the Murray Basin (Macphail 1999), and late Eocene at Zanthus, western Eucla Basin (Milne 1988).

Botanical affinity: Dicotyledonae

Tricolporites valvatus Harris 1971 (Plate 9, Fig. W)

Dimensions: Polar diameter 44 µm, equatorial diameter 25 µm (2 specimens)

Age range: Middle Eocene to early Pliocene in the Murray Basin (Macphail 1999), middle Eocene in the Otway Basin (Harris 1971), and late Eocene at Zanthus, western Eucla Basin (Milne 1988).

Botanical affinity: Ebenaceae, *Diospyros*-type (Dodson and Macphail 2004)

Tricolporopollenites pelargonioides Martin (1973b) (Plate 9, Figs N, O)

Dimensions: Equatorial diameter 39, 45 µm (2 specimens)

Age range: Miocene to Pliocene in the Lachlan River Valley (Martin 1973b)

Botanical affinity: Pelargonium (Martin 1973b)

5.3.4 Syncolpate and syncolporate pollen

Genus: *Cupanieidites* Cookson and Pike 1954

Type species: *Cupanieidites major* Cookson and Pike 1954

Cupanieidites major Cookson and Pike 1954 (Plate 10, Figs A–D)

Dimensions: Equatorial diameter 20 (22) 27 µm (11 specimens)

Remarks: Stover and Partridge (1973) combined *Cupanieidites major* and *C. orthoteichus*, as they could not determine a distinguishing character. Two distinct species are figured in Cookson and Pike (1954,) though the differences are minimally described in the text. In the Mulga Rock palynoflora, the *C. major* is distinguished by its thinner wall and the smaller to absent central island.

Age range: The combined age of *C. major* and *C. orthoteichus* in the Gippsland Basin ranges from the early Eocene to the upper Miocene (Stover and Partridge 1973).

Botanical affinity: Sapindaceae (soapberries), *Cupanieae* (Macphail 1999)

Cupanieidites orthoteichus Cookson and Pike 1954 (Plate 10, Figs E, F)

Dimensions: Equatorial diameter 15 (20) 26 µm (33 specimens)

Age range: Early Eocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973); middle Eocene to lower Pliocene in the Murray Basin (Macphail 1999); and late Palaeocene to middle Eocene in the Otway Basin (Harris 1971). It is known from the middle Eocene to late Eocene in Western Australia (Balme and Churchill 1959, Stover and Partridge 1982, Milne 1988).

Botanical affinity: Sapindaceae (soapberries), *Cupanieae* (Macphail 1999)

Cupanieidites reticularis Cookson and Pike 1954 (Plate 10, Figs G–J)

Dimensions: Equatorial diameter 16 (19) 26 µm (19 specimens)

Age range: Upper Eocene to upper lower Miocene in the Murray Basin (Macphail 1999). Present in palynofloras from the late Eocene Werillup Formation, WA (Hos 1975).

Botanical affinity: Sapindaceae (soapberries), *Cupanieae* (Macphail 1999)

Genus: *Gothanipollis* Krutzsch 1959

Type species: *Gothanipollis gothani* Krutzsch 1959

Gothanipollis bassensis Stover in Stover and Partridge 1973 (Plate 10, Figs K, L)

Dimensions: Equatorial diameter 14 (17) 22 µm (13 specimens)

Remarks: All specimens of *Gothanipollis bassensis* in the Mulga Rock palynoflora are syntricolpate. In most cases the grains are significantly folded.

Age range: Middle Eocene to Early Oligocene in the Gippsland Basin (Stover and Partridge 1973). Middle Eocene to middle Miocene in the Murray Basin (Macphail 1999) and late Eocene to early Oligocene in the eastern Eucla Basin (Alley and Benbow 1989). In southern Western Australia, it is recorded from the middle to late Eocene in the former Bremer Basin (Stover and Partridge 1982) and the late Eocene at Zanthus (Milne 1988).

Botanical affinity: Loranthaceae (Macphail 1999)

Genus: *Myrtaceidites* (Cookson and Pike) emend. Potonié 1960

Type species: *Myrtaceidites eucalyptoides* (Cookson and Pike) emend. Potonié 1960

Myrtaceidites eucalyptoides Cookson and Pike 1954 (Plate 10, Figs M–O)

Dimensions: Equatorial diameter 9 (15) 18 µm (42 specimens)

Remarks: Thornhill and Macphail (2012) combined the two forms described by Cookson and Pike (1954). This formed such a broad range of characteristics assignable to *Myrtaceidites eucalyptoides* that it likely includes several species. In the Mulga Rock palynoflora a distinctly convex form can be separated from *M. eucalyptoides* and is described as a new species in Chapter 6. The specimens assigned to *M. eucalyptoides* in this study have straight to slightly convex or concave sides, with an exine that thickens at the pores.

Age range: First appears in the Gippsland Basin in the upper Early Oligocene. Middle Eocene to Pleistocene in the Murray Basin (Macphail 1999) and present in sediments of late Eocene age at Zanthus, WA (Milne 1988).

Botanical affinity: Myrtaceae, *Corymbia* (Hill and Johnson 1995) (Bloodwood group) (Dodson and Macphail 2004)

Myrtaceidites mesonesus* / *parvus Cookson and Pike 1954 (Plate 10, Figs P, Q)

Dimensions: Equatorial diameter 9 (12) 19 µm (43 specimens)

Remarks: Myrtaceidites mesonesus and *M. parvus* are morphologically similar as described by Cookson and Pike (1954). A distinctly differing amb shape, with *M. parvus* described as more convex, is not apparent in the Mulga Rock palynoflora and the grains follow a continuum.

Age range: Myrtaceidites mesonesus ranges in age from Palaeocene to Pliocene, and *M. parvus* from Late Cretaceous to Pliocene (Thornhill and Macphail 2012).

Botanical affinity: ***Myrtaceidites mesonesus*** is aligned with *Eucalyptus* (Cookson & Pike 1954, Martin 1973, Thornhill & Macphail 2012); the affinity of ***M. parvus*** is currently unknown but resembles *Baeckea* L., *Tristania* R. Br. (Martin 1978), *Kunzea* Rchb. and *Leptospermum* Forst. & G. Forst (Truswell 1983)

5.3.5 Polycolpate pollen

Genus: *Nothofagidites* (Couper) Potonié 1960

Type species: *Nothofagidites flemingii* (Couper) Potonié 1960

Remarks: Nothofagidites brachyspinulosus (Cookson) Harris 1965 and *N. incrassatus* Cookson 1959 have been grouped together for this study, due to the difficulty associated with identifying each separately. It has also been noted that these species

are not biostratigraphically significant in the mid to late Eocene. *Nothofagidites emarcidus* (Cookson) Harris 1965 and *N. heterus* (Cookson) Stover and Evans 1973 have been similarly grouped.

Nothofagidites brachyspinulosus* / *incrassatus (Plate 10, Figs R–W)

Dimensions: Equatorial diameter 15 (20) 27 µm (38 specimens)

Remarks: While *Nothofagidites brachyspinulosus* and *N. incrassatus* are grouped for the purpose of this study, it should be noted that the majority are distinctly specimens of *N. incrassatus*.

Age range: The combined age of *Nothofagidites brachyspinulosus* and *N. incrassatus* in southern Australia ranges from the early Palaeocene to the upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and middle Eocene to early Pliocene in the Murray Basin (Macphail 1999). In WA, the combined range is from middle Eocene to late Eocene (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Fagaceae, *Nothofagus* (*Fuscospora*) spp.

Nothofagidites emarcidus* / *heterus (Plate 10, Figs X–X and Plate 11, Fig. A)

Dimensions: Equatorial diameter 17 (22) 31 µm (60 specimens)

Age range: Nothofagidites emarcidus and *N. heterus* share a similar age range: early Eocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006), middle Eocene to early Pliocene in the Murray Basin (Macphail 1999), Late Cretaceous to middle Miocene in the Otway Basin (Harris 1971), and middle to late Eocene in WA (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Fagaceae, *Nothofagus* (*Brassospora*) spp.

Nothofagidites falcatus (Cookson 1959) Hekel 1972 (Plate 11, Figs B–G)

Dimensions: Equatorial diameter 18 (23) 29 µm (36 specimens)

Age range: Ranges from the early Oligocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006), middle Eocene to early Pliocene in the Murray Basin (Macphail 1999). Oligocene to middle Miocene in the Otway Basin (Harris 1971) and middle to late Eocene in WA (Stover and Partridge 1982, Milne 1988)

Botanical affinity: Fagaceae, *Nothofagus* (*Brassospora*) spp.

Nothofagidites longispinosus (Couper) Pocknall in Dettmann *et al.* 1990 (Plate 11, Figs H, I)

Dimensions: Equatorial diameter 22 (29) 30 (3 specimens)

Age range: In Australia, *Nothofagidites longispinosus* is only known from middle Eocene sediments in the Murray Basin (Macphail 1999) and the late Eocene at Zanthus, WA (Milne 1988). In New Zealand it is restricted to the Pliocene (Veblen *et al.* 1996).

Botanical affinity: Fagaceae, *Nothofagus* (*Brassospora)* spp.

Nothofagidites senectus Dettman and Playford 1968 (Plate 11, Figs J–L)

Dimensions: Equatorial diameter 17 (19) 23 µm (11 specimens)

Age range: Ranges from the Middle to Late Cretaceous to the early Palaeocene in the Gippsland Basin, and of Late Cretaceous age in the Otway Basin (Harris 1971). It has not been previously recorded in WA.

Botanical affinity: Fagaceae, *Nothofagus* (more consistent with *Fuscospora*) spp.

Nothofagidites spinosus (Couper 1960) Mildenhall and Pocknall 1989 (Plate 11, Figs M–O)

Dimensions: Equatorial diameter 29 µm (1 specimen)

Age range: Of limited record in Australia; middle to late Eocene in Queensland (Foster 1982). It is also recorded offshore of Australia in sediments of late Eocene to Oligocene age near Tasmania (Haskell and Wilson 1975). In New Zealand it ranges from middle Miocene to Pleistocene (Mildenhall and Pocknall 1989)

Botanical affinity: Fagaceae, *Nothofagus* (*Brassospora*) spp.

Nothofagidites vansteenisii (Cookson 1959) Stover and Evans 1973 (Plate 11, Figs P–R)

Dimensions: Equatorial diameter 18 (22) 22 µm (5 specimens)

Age range: Middle Eocene to the upper Miocene in the Gippsland Basin (Stover and Partridge 1973), middle Eocene to lower Pliocene in the Murray Basin (Macphail 1999), and late Eocene to early Miocene in the Otway Basin (Harris 1971). Recorded in Late Eocene sediments at Zanthus, WA (Milne 1988).

Botanical affinity: Fagaceae, *Nothofagus* (*Brassospora* but distinct from extant species) spp.

5.3.6 Polycolporate pollen

Genus: *Polycolporopollenites* Kedves 1965

Type species: *Polycolporopollenites ellipticus* Kedves 1965

Polycolporopollenites esobalteus (McIntyre) Pocknall and Mildenhall 1984
(Plate 11, Figs T–W)

Dimensions: Polar diameter 17 (22) 30 µm, equatorial diameter 14 (18.5) 22 µm (24 specimens)

Age range: Early Eocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); middle Eocene through middle Miocene in the Gippsland Basin (Macphail 1999); and middle Eocene to late Eocene in southern WA (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Polygalaceae, *Polygala, Comesperma* (milkworts or snakeroots) (Macphail and Cantrill 2006)

Genus: *Psilastephanocolporites* Leidelmeyer 1966

Type species: *Psilastephanocolporites fissilis*

Psilastephanocolporites micus Partridge in Stover and Partridge 1973 (Plate 11, Fig. S)

Dimensions: Equatorial diameter 15 (19) 25 µm (22 specimens)

Age range: Mid-early Oligocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and upper Eocene to middle Miocene in the Murray Basin (Macphail 1999). In South Australia, it ranges from the middle Eocene to early Oligocene (Alley and Benbow 1989, Alley *et al.* 1996). *Psilastephanocolporites micus* was recorded in the late Eocene in southern WA, at Zanthus (Milne 1988).

Botanical affinity: extinct angiosperm (Macphail 1999)

5.3.7 Tetracolporate pollen

Genus: *Sapotaceoidaepollenites* (Potonié) Thomson and Thiergart 1950

Type species: *Sapotaceoidaepollenites manifestus* (Potonié) Thomson and Thiergart 1950

Sapotaceoidaepollenites latizonatus (McIntyre) Pocknall and Mildenhall 1984 (Plate 12, Figs A–C)

Dimensions: Polar diameter 20 µm, equatorial diameter 15 µm (1 specimen)

Age range: Early Eocene to middle Miocene in the Murray Basin (Macphail 1999). It was also recorded in sediments of early to middle Oligocene age in Tasmania (Macphail 1994). This is the first record of the species in WA.

Botanical affinity: Sapotaceae (Dodson and Macphail 2004)

Sapotaceoidaepollenites rotundus Harris 1972 (Plate 12, Figs D–F)

Dimensions: Polar diameter 17 (25) 33 µm, equatorial diameter 14 (19) 21 µm (25 specimens)

Age range: Upper early Eocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); early Eocene to middle Miocene in the Murray Basin (Macphail 1999); and middle to late Eocene in the Otway Basin (Harris 1971). In South Australia it ranges from middle Eocene to early Oligocene (Alley and Benbow 1989, Alley *et al.* 1996). In WA it is present in sediments ranging from middle to late Eocene age (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Sapotaceae (Macphail 1999)

Genus: *Tetracolporites* Couper 1953

Type species: *Tetracolporites oamaruensis* Couper 1953

Tetracolporites palynius Stover and Partridge 1982 (Plate 12, Figs G–I)

Dimensions: Equatorial diameter 28 (31.5) 35 µm (12 specimens)

Age range: Late Eocene to middle Miocene in the Murray Basin (Macphail 1999) and middle Eocene in South Australia at Nelly Creek (Alley *et al.* 1996). In WA, it ranges from middle to late Eocene in age (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Meliaceae, *Dysoxylum* (mahogany) (Macphail 1999)

Genus: *Tetracolporopollenites* Thomson 1953

Type species: *Tetracolporopollenites occultus* Thomson 1953

***Tetracolporopollenites* sp.** Milne 1988 (Plate 12, Figs J, K)

Dimensions: Polar diameter 20 (23) 26 µm, equatorial diameter 16 (18) 20 µm (7 specimens)

Age range: Only recorded from late Eocene sediments at Zanthus, WA (Milne 1988).

Botanical affinity: unknown

5.3.8 Hexaporate pollen

Genus: *Anacolosidites* Cookson and Pike 1954

Type species: *Anacolosidites acutullus* Cookson and Pike 1954

Anacolosidites acutullus Cookson and Pike 1954 (Plate 12, Figs L–O)

Dimensions: Equatorial diameter 20 (29) 35 µm (15 specimens)

Age range: Early-middle Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006). Middle to upper Eocene in the Murray Basin (Macphail 1999) and middle Palaeocene to late Eocene in the Otway Basin (Harris 1971). Late Eocene at Zanthus in the western Eucla Basin (Milne 1988).

Botanical affinity: Olacaceae**,** *Anacolosa* (Macphail 1999)

Anacolosidites luteoides Cookson and Pike 1954 (Plate 12, Figs S–U)

Dimensions: Equatorial diameter 11 (14) 21 µm (12 specimens)

Remarks: The morphology of *Anacolosidites luteoides* in the Mulga Rock palynoflora is variable, with three forms observed: smaller specimens with a thin, undifferentiated exine; specimens with a thick, distinctly stratified exine and circular pores; and specimens with significant mesoporial thickening and lalongate pores. More than one species may be represented here, but all three have been figured in publications as *A. luteoides.* There are too few specimens observed in the Mulga Rock palynoflora to make a distinction.

Age range: Early to upper middle Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); middle Eocene in the Murray Basin (Macphail 1999) and middle Palaeocene to late Eocene in the Otway Basin (Harris 1971). Present in the middle to late Eocene Werillup Formation in the former Bremer Basin, WA (Stover and Partridge 1982).

Botanical affinity: Olacaceae**,** *Anacolosa* (Macphail 1999)

5.3.9 Diporate pollen

Genus: *Banksieaeidites* Cookson ex Couper 1954

Type species: *Banksieaeidites elongatus* Cookson ex Couper 1954

Banksieaeidites arcuatus Stover in Stover and Partridge 1973 (Plate 12, Figs V–Z)

Emended description (TLM): Pollen diporate, anisopolar, amb in equatorial view elliptical with truncated ends, one side strongly convex, one side straight. Rare immature specimens are biconvex, where mounting medium has supported the grain on the straight side. Exine 0.5-1.5 µm, thinning to the aperture, rarely thickening in more immature specimens, indistinctly to distinctly stratified; nexine thicker than exine. Nexine thickens slightly towards aperture in some specimens. Rare specimens show a slight notch in the nexine prior to the development of the apertural collar. Apertures circular to slightly lalongate, 2-5 µm in diameter, widening with maturity, with ragged margins. Apertural collar present in most cases, though indistinct in some grains, 1-2.75 µm deep. Sexine psilate to faintly microscabrate.

Sculptural detail (SEM): Memon (1984) describes the exine of *B. arcuatus* as scabro-rugulo-foveolate. Based on the specimen figured in this paper it is more correct to refer to the sculpture as scabro-rugulo-perforate as foveolar refer to depressions greater than 1 µm in diameter (Punt *et al*. 2007).

Dimensions: 15 (20) 24 µm, width 9 (12) 13 µm (34 specimens)

Remarks: Specimens of *B. arcuatus* in Mulga Rock sediments are significantly smaller than those measured in Stover and Partridge (1973).

Age range: Upper early Eocene through late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and early Eocene to middle Miocene in the Murray Basin (Macphail 1999). In WA, it is recorded from the middle to late Eocene in the former Bremer Basin and the late Eocene at Zanthus (Milne 1988).

Botanical affinity: Proteaceae, Musgraveinae (Macphail 1999)

5.3.10 Tricolpoid pollen

Genus: *Beaupreaidites* Cookson ex Couper (1953)

Type species: *Beaupreaidites elegansiformis* Cookson ex Couper (1953)

Beaupreaidites diversiformis Milne 1988 (Plate 12, Figs AA–CC and Plate 13, Figs A–C)

Dimensions: Equatorial diameter 26 (39) 51 µm (30 specimens)

Age range: Beaupreaidites diversiformis ranges from middle Eocene to Oligocene in Australia (Milne 1998).

Botanical affinity: Proteaceae, Conospermeae, *Beauprea* (Milne 1998)

Beaupreaidites elegansiformis Cookson 1950 (Plate 13, Figs D–F)

Dimensions: Equatorial diameter 25 (33) 45 µm (47 specimens)

Age range: Records of *Beaupreaidites elegansiformis* range from Late Campanian to early Pleistocene, though the most recent record of the species in Australia is from the late Pliocene (Milne 1998).

Botanical affinity: Proteaceae, Conospermae, *Beauprea* (particularly *Beauprea spathulaefolia*) (Milne 1998)

Beaupreaidites verrucosus Cookson 1950 (Plate 13, Figs G–I)

Dimensions: Equatorial diameter 29 (38) 42 µm (25 specimens)

Remarks: Middle Eocene to early Miocene in the Murray Basin (Macphail 1999). In Western Australia it is known from the Zanthus palynoflora (Milne 1988) and from palaeochannel sediments at Coolgardie (Balme and Churchill 1959).

Botanical affinity: Proteacidites, Conospermeae, *Beauprea* (Milne 1998)

5.3.11 Triporate pollen

Genus: *Bluffopollis* Pocknall and Mildenhall 1984

Type species: *Bluffopollis scabratus* (Couper 1954) Pocknall and Mildenhall 1984

Bluffopollis scabratus (Couper 1954) Pocknall and Mildenhall 1984 (Plate 7, Figs K–M)

Dimensions: Equatorial diameter 16 (22) 27 µm (29 specimens)

Age range: Upper Eocene to upper lower Miocene in the Murray Basin (Macphail 1999). Middle Eocene in the Otway Basin (Harris 1971). In southern Western Australia, it is recorded from the middle to late Eocene in the Werillup Formation, former Bremer Basin (Stover and Partridge 1982), and the late Eocene at Zanthus in the western Eucla Basin (Milne 1988).

Botanical affinity: Strasburgeriaceae**,** *Strasburgeria* (Macphail 1999)

Genus: *Haloragacidites* Couper 1953

Type species: *Haloragacidites trioratus* Couper 1953

Haloragacidites harrisii (Couper) Harris 1971 (Plate 14, Figs A–D)

Dimensions: Equatorial diameter 17 (27) 36 µm (40 specimens)

Remarks: Haloragacidites harrisii is highly variable in the Mulga Rock palynoflora, and contains a number of morphotypes with some aberrant biporate forms also observed.

Age range: Palaeocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and early Eocene to Pleistocene in the Murray Basin (Macphail 1999). Ranges from middle Eocene in the former Bremer Basin (Stover and Partridge 1973) to early Pliocene at Lake Tay (Bint 1981).

Botanical affinity: Casuarinaceae, *Casuarina/Gymnostoma* (Macphail 1999)

Genus: *Propylipollis* Martin and Harris 1974

Type species: *Propylipollis reticuloscabratus* (Harris) Martin and Harris 1974

Propylipollis biporus Dudgeon 1983 (Plate 14, Figs I, J)

Dimensions: Equatorial diameter 27 (31) 38 µm (5 specimens)

Age range: Middle Eocene to Miocene in the Murray Basin (Macphail 1999), Middle Eocene in the Yamba Basin, QLD (Dudgeon 1983), and late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: Proteaceae (Macphail 1999)

Propylipollis robustus Dudgeon 1983 (Plate 14, Figs K–M)

Dimensions: Equatorial diameter 18 (29) 36 µm (15 specimens)

Age range: Early Miocene to late Oligocene in Queensland (Wood 1986) and late Eocene at Zanthus in southern WA (Milne 1988).

Botanical affinity: Proteaceae

***Propylipollis* sp. A** Milne 1988 (Plate 14, Figs N, O)

Dimensions: Equatorial diameter 23 µm (1 specimen)

Age range: Only known from Zanthus in WA, of late Eocene age (Milne 1988)

Botanical affinity: Proteaceae

***Propylipollis* sp. B** Milne 1988 (Plate 14, Figs P–R)

Dimensions: 19, 20 µm (2 specimens)

Age range: Only known from Zanthus in WA, of late Eocene age (Milne 1988)

Botanical affinity: Proteaceae

Genus: *Proteacidites* Cookson ex Couper 1953

Type species: *Proteacidites adenanthoides* Cookson 1950, by subsequent designation of Couper (1953)

Proteacidites adenanthoides Cookson 1950 (Plate 14, Figs S–U)

Dimensions: Equatorial diameter 28 (32) 39 µm (13 specimens)

Remarks: Specimens of *Proteacidites adenanthoides* in the Mulga Rock palynoflora are sculpturally identical to the description in Stover and Partridge (1973) and Cookson (1950), and share the same wall and aperture structure. They differ in that they are smaller with significantly smaller apertures. The size range given in Stover and Partridge 1973 and Cookson (1950) is 44–75 µm and 32–48 µm respectively. The single specimen observed in a palynoflora from Ivanhoe measured 37 µm. Aperture widths range from 3–6 µm for specimens found elsewhere in southern Australia, but measure 1.5–2.5 µm in Mulga Rock specimens. As Gippsland Basin specimens (Stover and Partridge 1973) reach 75 µm in length, it is possible the smaller apertures at Mulga Rock are due to the smaller grain size. The specimen figured in Hos (1975) from the Werillup Formation also appears to share the smaller apertures observed in Mulga Rock specimens. All specimens observed in the Mulga Rock

assemblages possess concave sides, though Cookson (1950) described the amb as straight to convex. Cookson (1950) also noted that the nexine doesn't thin to the apertures, but the amendment by Stover and Partridge (1973) describes the nexine as thinning right to the aperture. Significant thinning of the nexine is observed in Mulga Rock specimens directly at the apertures.

Age range: Late Palaeocene to late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); early Eocene to lowermost Oligocene in the Murray Basin (Macphail 1999); middle Palaeocene to late Eocene in the Otway Basin (Harris 1971); and middle to late Eocene in WA (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Proteaceae, *Adenanthera* (Macphail 1999)

Proteacidites alveolatus Stover in Stover and Partridge 1973 (Plate 15, Figs A, B)

Dimensions: Equatorial diameter 29 µm (1 specimen)

Remarks: The sole specimen of *Proteacidites alveolatus* is of slightly smaller size than the range of 32–42 µm described for the Gippsland Basin specimens. This may explain the slightly smaller aperture size (2.5 µm compared to 3–5 µm) measured for the Mulga Rock specimen. The specimen figured in Milne (1988) measured 34 µm in diameter. The sculpture is obscure in the Mulga Rock specimen, with the perforations in the muri described by Stover and Partridge (1973) not apparent. A thickening of the nexine was also observed in the Mulga Rock specimen, with the total thickness of the exine measuring 1.5 µm interradially and 2 µm at the aperture. Stover and Partridge (1973) only noted that the nexine was indistinct at the aperture and while this remains the case in the Mulga Rock specimen, it was distinguishable enough to measure.

Age range: Mid-early Eocene to upper middle Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: Proteaceae

Proteacidites annularis Cookson 1950 (Plate 15, Figs C, D)

Dimensions: Equatorial diameter 16 (21) 37 µm (53 specimens)

Remarks: The specimens of *Proteacidites annularis* in the Mulga Rock palynoflora extend the size range, previously stated as 27–37 µm (Cookson 1950) and 21–37 µm (Milne 1994). Milne (1994) noted a variable aperture form, with the aperture widening as the pollen grain matured. Both immature forms and mature forms as

figured by Milne (1994) were observed in the Mulga Rock palynoflora, as well as transitional forms. Several specimens had an exine thinner than those observed in Milne (1994), with the thinnest measuring 0.75 µm. The wall stratification in these specimens was indistinct and the thinner wall may be due to stripping of the sexine. Aperture width ranged from 3–9 µm and collar depth from 2.5–8 µm.

Age range: Palaeocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); early Eocene to middle Miocene in the Murray Basin (Macphail 1999); late Palaeocene to Oligocene in the Otway Basin (Harris 1971); and late Eocene to early Oligocene in palaeochannel sediments at Coolgardie (Balme and Churchill 1959).

Botanical affinity: Proteaceae, *Xylomelum occidentale* (Milne 1994)

Proteacidites annularis (verrucate) Cookson 1950 (Plate 15, Figs E–G)

Dimensions: Equatorial diameter 26 (27) 35 µm (3 specimens)

Remarks: Proteacidites cf. *annularis* differs from other specimens of *P. annularis* in that it possesses verrucae of 1–2 µm in diameter variably distributed across the grain. Verrucate specimens are larger than the median grain size of *P. annularis*.

Botanical affinity: Proteaceae, likely *Xylomelum*

Proteacidites beddoesii Stover and Partridge 1973 (Plate 15, Fig. H)

Dimensions: 26, 31 µm (2 specimens)

Remarks: The smaller specimen possesses smaller apertures and less distinct apiculae, if these are present at all. This could be due to immaturity of the grain. The larger specimen is as described by Stover and Partridge (1973).

Age range: Early to late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and upper Eocene in the Murray Basin (Macphail 1999). Not previously recorded from WA.

Botanical affinity: Proteaceae

Proteacidites bremerensis Stover and Partridge 1982 (Plate 15, Figs I–K)

Dimensions: Equatorial diameter 28, 31 µm (2 specimens)

Remarks: The specimens of *Proteacidites bremerensis* observed in the Mulga Rock palynoflora are distinctly smaller than those described from the Gippsland Basin, with Stover and Partridge (1973) stating a range in diameter of 44–57 µm. The two

specimens from Zanthus (Milne 1988) are of a similar size to the Mulga Rock specimens, measuring 29 and 30 µm. The larger and irregularly shaped collumelae described for Gippsland Basin specimens are lacking in the Mulga Rock specimens, with only circular collumelae of less than 0.5 µm diameter observed.

Age range: Middle to late Eocene in WA (Stover and Partridge 1982, Milne 1988). Not recorded elsewhere in Australia.

Botanical affinity: Proteaceae

Proteacidites carobelindiae Milne 1988 (Plate 15, Figs L–O)

Dimensions: Equatorial diameter 17 (22) 28 µm (42 specimens)

Remarks: The Mulga Rock specimens of *Proteacidites carobelindiae* are smaller than the specimens described in Milne (1998). The Moorlands specimens in Milne (1998) were also preserved in 'Eukitt' and ranged from 20–32 µm in length. The reticulum of the Mulga Rock specimens is finer, with the lumina reaching a maximum diameter of 0.5 µm, though they reach up to 1 µm for circular forms and 2 µm where more elongate. The elongate lumina are rarely seen in the Mulga Rock specimens, with the majority showing a reticulum made up of circular lumina and muri of a width close to the lumina diameter. Like the holotype, many of the Mulga Rock specimens are slightly convex, with only one or two with straight sides. All apertural forms described in Milne (1998) were observed.

Age range: Late Eocene in Western Australia (Balladonia and Zanthus) and middle to late Eocene in South Australia (Milne 1998). The inclusion of *Proteacidites carobelindiae* in many studies as either *Beaupreaidites elegansiformis* or *B.* spp. means that it may have a wider distribution in southern Australian Cenozoic sediments (Milne 1998).

Botanical affinity: Proteaceae, Conospermeae (Proteoideae), possibly with *Petrophile* (Milne 1998)

Proteacidites cirritulus Milne 1988 (Plate 15, Figs P–R)

Dimensions: Equatorial diameter 11 (15) 21 µm (55 specimens)

Remarks: Several specimens from the Mulga Rock palynoflora had a coarser reticulum than that described by Milne (1998), with polygonal lumina reaching up to 1.25 µm in diameter.

Age range: Late Eocene in Western Australia at Balladonia (Milne 1998) and Zanthus (Milne 1988). Milne (1998) noted that *Proteacidites cirritulus* had been previously assigned to other small proteaceous taxa and rarely illustrated by other workers, and that the range of *Proteacidites cirritulus* may be more extensive in the Cenozoic of Australia. It may range into the Pliocene but the range of the specimen of that age (Macphail 1996) was not formally included by Milne (1998).

Botanical affinity: Proteaceae, Conospermeae (Proteoideae), *Petrophile* (Milne 1998)

Proteacidites confragosus Harris 1972 (Plate 15, Figs S, T)

Dimensions: Equatorial diameter 35 (51) 66 µm (17 specimens)

Remarks: Specimens of *Proteacidites confragosus* illustrated previously are variable. Harris (1971) described it as slightly convex, with lumina measuring 3–4 µm. Several specimens meeting this description were present in the Mulga Rock palynoflora. Others possess larger lumina (3–7 µm) but otherwise conform to the Harris (1971) description. The larger lumina are more elongate, and are 2.5 µm wide. These specimens are also slightly more convex. A similar specimen was figured in Milne (1988). Many of these forms possess damaged and partially stripped sexines, and the only method of identifying these specimens are the muri made up of closely spaced baculae. These differences are however, only slight and the two forms are still assigned to *Proteacidites confragosus* in this study.

Age range: Middle Eocene in the Otway Basin (Harris 1971), upper Eocene to lowermost Oligocene in the Murray Basin (Macphail 1999), and middle to late Eocene in WA (Stover and Partridge 1982, Milne 1988)

Botanical affinity: Proteaceae

Proteacidites crassus Cookson 1950 (Plate 16, Figs A–E)

Dimensions: Equatorial diameter 24 (32.5) 43 µm (42 specimens)

Remarks: Pollen assigned to *Proteacidites crassus* in this study are of variable form, all sharing a sculpture as described by Cookson (1950), and by Stover and Partridge (1973) in their remarks upon the lectotype. A larger form that is strongly convex with the amb thinning towards the apertures is most similar to that illustrated by Cookson (1950) and Stover and Partridge (1973). A similar form was figured in Alley and Broadbridge (1992) and Macphail (1999). The apertures of these forms are slightly smaller than the 5 µm described in Stover and Partridge (1973). A smaller form, with

straighter sides, but otherwise identical to previous descriptions of *P. crassus*, was observed in Mulga Rock flora. Similar forms have been figured by Foster (1982, *Proteacidites* sp. A, Plate 7, Fig. 1) and Hekel (1972, *Proteacidites* sp. aff. *P. crassus*, Plate 5, Fig. 16). As specimens between this form and the form illustrated by Cookson (1950) and Stover and Partridge (1973) were observed in the Mulga Rock palynoflora, the smaller form is included within *P. crassus* here. The aberrant form illustrated in Milne (1988) was also found in the Mulga Rock palynoflora, with one to two additional apertures.

Age range: Upper early Eocene to late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 1976, Partridge 2006); middle Eocene to lowermost Oligocene in the Murray Basin (Macphail 1999); and middle Palaeocene in the Otway Basin (Harris 1971). Milne (1988) notes that *P. crassus* is present in most Eocene palynofloras. In WA, it is recorded from middle to late Eocene from the former Bremer Basin and the western Eucla Basin (Milne 1988). It is also present in late Eocene to early Oligocene palaeochannel sediments at Coolgardie (Balme and Churchill 1959).

Botanical affinity: Proteaceae, possibly *Adenanthos*

Proteacidites cumulus Stover and Partridge 1982 (Plate 16, Figs F, G)

Dimensions: Equatorial diameter 25 (34) 43 µm (25 specimens)

Remarks: Specimens of *Proteacidites cumulus* in the Mulga Rock palynoflora are identical to the description of Stover and Partridge (1982). The Mulga Rock specimens are smaller, but these were mounted in 'Eukitt', rather than glycerine jelly as in Stover and Partridge's (1973) study. Stover and Partridge (1982) described a thickening of the nexine prior to the aperture, which is also apparent in the Mulga Rock specimens. A slight notch, 0.25–0.5 µm deep and less than 0.5 µm wide was noted just prior to this thickening of the nexine. The gemmae coalesce in a Y-shaped pattern in the grain centre, as described by Milne (1988).

Age range: Only currently known from southern WA palynofloras. Upper middle through late Eocene in the former Bremer Basin (Stover and Partridge 1982, Partridge 2006) and late Eocene at Zanthus (Milne 1988).

Botanical affinity: Proteaceae

Proteacidites* cf. *grandis Cookson 1950 (Plate 16, Figs H, I)

Dimensions: 46, 51 µm (2 specimens)

Remarks: Proteacidites cf. *grandis* is very similar to *P. grandis*, except the Mulga Rock specimens are slightly convex rather than moderately to deeply convex (Cookson 1950, Stover and Partridge 1973) and the lumina are smaller (1.5–2.5 µm). *Proteacidites* cf. *grandis* is also significantly smaller than Gippsland Basin specimens. Cookson (1950) stated that the exine thins towards the apertures, but this does not appear to be the case in both the specimen she illustrated, and also in *P.* cf. *grandis*.

Botanical affinity: Proteaceae

Proteacidites* aff. *Grevillea (Plate 16, Figs J, K)

Dimensions: Equatorial diameter 41, 43 µm (2 specimens)

Remarks: Refers to two different species, here grouped due to their morphological similarity to extant *Grevillea* pollen. Both specimens share an exine with a significantly thicker nexine (4 µm) than sexine (0.5–1 µm). The 41 µm specimen has two expanded apertures (13 µm) and one (10 µm), preserving a cap similar to that observed in *P. annularis*. A finely scabrate exine was observed for this specimen. The second possesses expanded apertures encircled with a band of nexine. This grain was reticulate, with circular to polygonal lumina 1–2 µm in diameter, with 0.5 µm wide muri, underlain with single collumelae less than 0.5 µm in diameter.

Botanical affinity: Proteaceae, possibly *Grevillea*

Proteacidites* aff. *Isopogon (Plate 16, Fig. L)

Dimensions: Equatorial diameter 22 (27) 35 µm (7 specimens)

Remarks: Fossil species discussed here resemble pollen of extant *Isopogon*, grains of which possess an expanded aperture that appears truncate. Two distinct forms were recognised; two specimens with a granulate sculpture and a straight sided amb, and a psilate form that is often stripped of the sexine with a convex amb. Both *Proteacidites isopogiformis* Couper (1960) and *P. truncatus* Cookson (1950) were also aligned with *Isopogon* but both possess a reticulate exine rather than granulate or psilate.

Botanical affinity: Proteaceae, possibly *Isopogon*

Proteacidites ivanhoensis Martin 1973 (Plate 16, Fig. M)

Dimensions: Equatorial diameter 15 (18) 24 µm (6 specimens)

Remarks: Larger specimens in the Mulga Rock palynoflora are strongly similar to those described by Martin (1973) at Ivanhoe. The size range is smaller than the Ivanhoe specimens, with the largest equalling the median size given in Martin (1973). Smaller specimens in the Mulga Rock palynoflora have a less distinct morphology but are retained here. The reticulum described by Martin (1973) is difficult to discern, but the lumina measured 0.5 µm in diameter in the Ivanhoe specimens, which is on the margin of what can be observed with transmitted light microscopy.

Age range: Late Eocene to middle Miocene in the Murray Basin (Macphail 1999). Late Eocene in WA (Milne 1988).

Botanical affinity: Proteaceae, *Orites* (Macphail 1999)

Proteacidites kopiensis Harris 1972 emend. Dudgeon 1983 (Plate 17, Figs A, B)

Dimensions: Equatorial diameter 36 µm (1 specimen)

Remarks: The specimen of *Proteacidites kopiensis* at Mulga Rock is on the smaller side of the size range given by both Harris (1972, 35-49 µm) and Dudgeon (1983, 36-47 µm). Dudgeon (1983) described specimens with a reticulum that fined to the poles and apertures, while Harris (1972) only recognised a fining to the apertures. The Mulga Rocks specimen fines rapidly to the poles and apertures. It is also distinctly anisopolar, possessing a polar boss on the proximal side, which was not noted in Harris (1972). A polar boss was not described in Dudgeon (1983) but does seem to be apparent in the illustrations.

Age range: Early to late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); late Palaeocene to middle Eocene in the Otway Basin (Harris 1971); Middle Eocene in the Yamba Basin, QLD (Dudgeon 1983), and middle to late Eocene in WA (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Proteaceae

Proteacidites leightonii Stover in Stover and Partridge 1973 (Plate 17, Fig. E)

Dimensions: Equatorial diameter 41, 44 µm (2 specimens)

Remarks: The Mulga Rock specimens of *Proteacidites leightonii* are smaller than the 62–75 µm range given by Stover and Partridge (1973). The Mulga Rock specimens are strongly similar, though the nexine is slightly thicker, rather than equal to, the sexine.

Age range: Early Eocene through late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and middle to late Eocene in the Murray Basin (Macphail 1999). Present in southern WA in the late Eocene Werillup Formation in the former Bremer Basin (Stover and Partridge 1982) and in the late Eocene Zanthus assemblage (Milne 1988).

Botanical affinity: Proteaceae

Proteacidites* cf. *leightonii Stover in Stover and Partridge 1973 (Plate 17, Figs C, D)

Dimensions: Equatorial diameter 32 (35) 42 µm (5 specimens)

Remarks: These specimens are similar to *Proteacidites leightonii*, except the muri are thinner and made up of larger collumelae (0.75 µm) that are spaced further apart, isolating them from each other. The lumina are of similar size to those of *P. leightonii*, ranging from 1.5 to 5µm in diameter.

Botanical affinity: Proteaceae

Proteacidites* cf. *Propylipollis microverrucatus Truswell and Owen 1988 (Plate 17, Figs F, G)

Dimensions: Equatorial diameter 28 (40) 41 µm (3 specimens)

Remarks: Proteacidites cf. *P. microverrucatus* resembles *Propylipollis microverrucatus* Truswell and Owen (1988) as it has sculpture made up of angular microverrucae. The Mulga Rock specimens lack the atrium described for *P. microverrucatus*. Dudgeon (1983), as noted in Truswell and Owen (1988), did describe a specimen that resembles these as *P.* sp. cf. *Proteacidites rectomarginis.*

Botanical affinity: Proteaceae

Proteacidites nasus Truswell and Owen 1988 (Plate 17, Figs H–J)

Dimensions: Equatorial diameter 33 (38) 44 µm (19 specimens)

Remarks: Specimens of *Proteacidites nasus* in the Mulga Rock palynoflora are, in most part, morphologically identical to the description given in Truswell and Owen (1988). Some smaller and potentially less mature specimens possess a straight sided amb. The interradial lumina have a median diameter similar to the 3–3.5 µm given by Truswell and Owen, but can range up to 5 µm.

Age range: Upper Eocene in the Murray Basin (1999). Middle Eocene at Bungonia (Truswell and Owen 1988).

Botanical affinity: Proteaceae

***Proteacidites nasus* (small)** Truswell and Owen 1988 (Plate 17, Figs K–N)

Dimensions: Equatorial diameter 23 (27) 29 µm (5 specimens)

Remarks: These grains strongly resemble *Proteacidites nasus*, but are significantly smaller than the size range of 39–47 µm specified by Truswell and Owen (1988).

Botanical affinity: Proteaceae

Proteacidites* cf. *nexinus Pocknall and Mildenhall 1984 (Plate 18, Figs A–C)

Dimensions: Equatorial diameter 44 µm (1 specimen)

Remarks: Proteacidites cf. *nexinus* conforms to *P. nexinus* as described by Pocknall and Mildenhall 1984. The characters described by Pocknall and Mildenhall (1984) could cover a wide range of amb shapes, but list the thick nexine that thickens to the aperture as the distinguishing character. The nexine in the Mulga Rock specimen is 2.5 µm increasing to 3 µm at the aperture, and is significantly thicker than the exine. The reticulate sexine is also similar to that described for *P. nexinus*; 1 µm wide muri underlain by a single row of distinct collumelae and lumina mostly 3–4 µm in diameter.

Age range: Early Miocene in Southland, New Zealand. Listed here as cf. due to the late Eocene age of the Mulga Rock palynoflora.

Botanical affinity: Proteaceae, *Symphionema* (Milne and Martin 1998)

Proteacidites* cf. *nitidus Dudgeon 1983 (Plate 18, Figs D, E)

Dimensions: Equatorial diameter 24 (29) 35 µm (12 specimens)

Remarks: Proteacidites cf. *nitidus* possesses a sculpture that resembles *P. nitidus* Dudgeon 1983. It differs in that the amb is often straight to slightly concave rather than convex, and that the per-reticulum is slightly finer. The amb is similar to that of *P. punctiporus* Macphail and Truswell 1993, but the perforations at the apertures were not present in *P.* cf. *nitidus.*

Botanical affinity: Proteaceae

***Proteacidites* 'notredamus'** Milne ms. (Plate 18, Figs F, G)

Dimensions: Equatorial diameter 46 (53.5) 62 µm (16 specimens)

Remarks: Proteacidites notredamus strongly resembles *P. confragosus* Harris, but possesses significantly larger polygonal lumina (4–9 µm) and a muri made up of clavae (1–2.5 µm) rather than baculae.

Botanical affinity: Proteaceae

Proteacidites obscurus Cookson 1950 (Plate 18, Figs H–M)

Dimensions: Equatorial diameter 15 (20) 27 µm (45 specimens)

Remarks: Proteacidites obscurus is here assigned to pollen grains with the same exine structure and weakly attached sexine as described by Cookson 1950. While the majority of grains of *P. obscurus* in the Mulga Rock palynoflora share the baculate sculpture (42%, though possibly more as the sexine was entirely stripped from 38%) a variation of sculpture in a few specimens was observed. Four (9%) were baculate, but with bacula more closely spaced than in those specimens similar to Cookson's. One specimen showed grouping of the bacula as described for those specimens grouped into *P. varius* by Harris (1972). One grain possessed bacula grouped into rugulae, and two specimens (4%) were rugulate, with rugulae 0.5–1 µm wide.

Age range: Middle Eocene to middle Miocene in the Murray Basin (Macphail 1999), and middle to late Eocene in WA (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Proteaceae, *Agastachys* (Macphail 1999)

Proteacidites* cf. *ornatus Harris 1965 (Plate 19, Figs A–C)

Dimensions: Equatorial diameter 31 (39) 41 µm (5 specimens)

Remarks: Specimens of *Proteacidites ornatus* were described as angulaperturate. The specimens from Mulga Rock possess the same convoluted muri, though the lumina were smaller (1.5–5 µm), but have more rounded apices with circular apertures.

Botanical affinity: Proteaceae

Proteacidites pachypolus Cookson and Pike 1954 (Plate 19, Figs D–F)

Dimensions: Equatorial diameter 20 (26) 35 µm (49 specimens)

Age range: Mid-early Eocene through late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); early Eocene to middle Miocene in the Murray Basin (Macphail 1999); middle Eocene to late Palaeocene in the Otway Basin (Harris 1971); middle to late Eocene in the former Bremer Basin (Stover and Partridge 1982)

and the western Eucla Basin (Milne 1988); and late Eocene to early Oligocene in palaeochannel sediments at Coolgardie (Balme and Churchill 1959).

Botanical affinity: Proteaceae

Proteacidites pseudomoides Stover in Stover and Partridge 1973 (Plate 19, Figs G, H)

Dimensions: Equatorial diameter 15 (21) 25 µm (11 specimens)

Remarks: Specimens of *Proteacidites pseudomoides* in the Mulga Rock palynoflora are significantly smaller, with a finer reticulum than described in Stover and Partridge (1973).

Age range: Early Eocene into the early Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); upper Eocene to middle Miocene in the Murray Basin (Macphail 1999); and middle to late Eocene in the former Bremer Basin (Stover and Partridge 1982) and at Zanthus, WA (Milne 1988).

Botanical affinity: Proteaceae, *Lomatia* (Macphail 1999)

***Proteacidites* cf. *pseudomoides* sp. 1** Stover in Stover and Partridge 1973 (Plate 19, Figs I, J)

Dimensions: Equatorial diameter 18 (21) 21 µm (3 specimens)

Remarks: Proteacidites cf. *pseudomoides* sp. 1 is significantly smaller than *P. pseudomoides* and *P. symphyonemoides* Cookson (1950). *Proteacidites* cf. *pseudomoides* sp. 1 also differs in that the muri are significantly thinner and the lumina larger than the specimens herein assigned to *P. pseudomoides*. *Proteacidites* cf. *pseudomoides* is distinguished from *P. symphyonemoides* in having a thinner exine and a significantly smaller meshed reticulum.

Botanical affinity: Proteaceae, possibly *Lomatia* (Macphail 1999)

***Proteacidites* cf. *pseudomoides* sp. 2** Stover in Stover and Partridge 1973 (not illustrated)

Dimensions: Equatorial diameter 23 µm (1 specimen)

Remarks: The specimen assigned to *Proteacidites* cf. *pseudomoides* sp. 2 closely resembles *P.* cf. *pseudomoides* except that for a nexine that is up to three times thicker than the sexine.

Botanical affinity: Proteaceae, possibly *Lomatia* (Macphail 1999)

***Proteacidites* cf. *pseudomoides* sp. 3** Stover in Stover and Partridge 1973 (Plate 19, Fig. K)

Dimensions: Equatorial diameter 19 (21) 23 µm (3 specimens)

Remarks: Proteacidites cf. *pseudomoides* sp. 3 possesses a similar amb shape, aperture structure and exine stratification to *P. pseudomoides*, however it is tectate perforate, with 0.5 µm perforations consistent across the grain.

Botanical affinity: Proteaceae, possibly *Lomatia* (Macphail 1999)

Proteacidites punctiporus Macphail and Truswell 1993 (Plate 19, Figs L, M)

Dimensions: Equatorial diameter 28 (31) 34 µm (11 specimens)

Age range: Late Miocene to Pliocene in the central west Murray Basin, Pliocene in southwest Western Australia (Macphail and Truswell 1993).

Botanical affinity: Proteaceae, *Stirlingia* (Milne 1998)

Proteacidites rectomarginis Cookson 1950 (Plate 19, Figs N, O)

Dimensions: Equatorial diameter 52 µm (1 specimen)

Age range: Late Eocene into the upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 1976, Partridge 2006); upper Eocene to middle Miocene in the Murray Basin (Macphail 1999); late Eocene in the Otway Basin (Harris 1971); and late Eocene at Zanthus in the western Eucla Basin (Milne 1988).

Botanical affinity: Proteaceae

Proteacidites rectus Pocknall and Mildenhall 1984 (Plate 19, Figs P, Q)

Dimensions: Equatorial diameter 31, 38 µm (2 specimens)

Age range: Upper Eocene to lowermost Oligocene in the Murray Basin (Macphail 1999) and Late Eocene at Zanthus, WA (Milne 1988). In New Zealand, rare in the middle to late Eocene, common in Oligocene and early to middle Miocene (Pocknall and Mildenhall 1984).

Botanical affinity: Proteaceae

Proteacidites reticulatus Cookson 1950 (Plate 19, Figs R, S)

Dimensions: Equatorial diameter 21 (26) 35 µm (42 specimens)

Remarks: Specimens of *Proteacidites reticulatus* in the Mulga Rock palynoflora closely resemble those described by Cookson (1950) and Stover and Partridge (1973), with some variation. Several grains were anisopolar, rather than subisopolar, with a finer reticulum on one side (3–5 µm) and a coarser reticulum on the other (4–9 µm). One specimen was aberrant, possessing four apertures.

Age range: Early to middle Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); upper Eocene to lowermost Oligocene in the Murray Basin (Macphail 1999); and middle Palaeocene to late Eocene in the Otway Basin (Harris 1971). Present in the middle to late Eocene Werillup Formation (Stover and Partridge 1982) and in the late Eocene palynoflora from Zanthus, WA (Milne 1988).

Botanical affinity: Proteaceae

Proteacidites* cf. *reticulatus Cookson 1950 (Plate 20, Figs A–D)

Dimensions: Equatorial diameter 17 (25) 30 µm

Remarks: Proteacidites cf. *reticulatus* closely resembles specimens of *P. reticulatus* described by Cookson (1950) and Stover and Partridge (1973), but possesses a significantly finer reticulum. The muri in these specimens measure 0.5–1 µm wide, and the lumina 0.5–4 µm in diameter, though most are less than 2 µm.

Botanical affinity: Proteaceae

Proteacidites rynthius Stover and Partridge 1982 (Plate 20, Figs E–J)

Dimensions: Equatorial diameter 26 (37) 51 µm (12 specimens)

Remarks: The description of *Proteacidites rynthius* given by Stover and Partridge (1982) indicates that the nexine thins to the apertures. The specimens they figured, and those from Mulga Rock, instead possess a nexine that is either consistent across the grain, or thickens slightly at the aperture. They also described it as isopolar. Two of the Mulga Rock specimens are subisopolar, appearing to have a polar boss. The reticulate sexine of the Mulga Rock specimens is made up of muri <1 µm wide, enclosing lumina that range from 1–2 µm in diameter interradially, reducing to <0.5-0.5 µm at the apertures. One specimen appears to have a polar boss with a similar reduction in the lumina. Two size populations are also apparent with the smaller ranging from 27–31 µm and the larger from 37–50 µm. As only 11 specimens were examined these are here grouped.

Age range: Upper Eocene to lowermost Oligocene in the Murray Basin (Macphail 1999) and middle to late Eocene in WA (Stover and Partridge 1982, Milne 1988).

Botanical affinity: Proteaceae

Proteacidites scitus Stover and Partridge 1982 (Plate 20, Figs K, L)

Dimensions: Equatorial diameter 24 (25) 29 µm (3 specimens)

Remarks: Stover and Partridge (1982) describes the exine of *Proteacidites scitus* as thinning and incurved at the apertures. Stover and Partridge's (1982) figured specimen (Plate 5, 1b and 1c) appears to possess a nexine that remains consistent to the aperture prior to incurving. Specimens of *P. scitus* from Mulga Rock possess a similar exine structure.

Age range: Middle to late Eocene in the former Bremer Basin (Stover and Partridge 1982) and late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: Proteaceae

Proteacidites* cf. *scitus Stover and Partridge 1982 (not illustrated)

Dimensions: 29 µm (1 specimen)

Remarks: Proteacidites cf. *scitus* has a similar amb shape and exine structure to *P. scitus*, but lacks the delicate muri and comparatively large lumina. The muri of *P.* cf. *scitus* are 1 µm wide and enclose lumina of a similar diameter.

Botanical affinity: Proteaceae

Proteacidites* cf. *simplex Dudgeon 1983 (Plate 20, Figs M, N)

Dimensions: Equatorial diameter 29, 32 µm (2 specimens)

Remarks: Proteacidites cf. *simplex* differs from *Proteacidites simplex* in that it is isopolar and slightly larger than the size range specified by Dudgeon (1983).

Botanical affinity: Proteaceae

Proteacidites stipplatus Stover and Partridge 1973 (not illustrated)

Dimensions: 31 µm (1 specimen)

Age range: Middle Eocene to the early Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); upper Eocene to middle Miocene in the Murray Basin (Macphail 1999); and late Eocene at Zanthus, western Eucla Basin (Milne 1988).

Botanical affinity: Proteaceae

Proteacidites* cf. *stipplatus Stover and Partridge 1973 (Plate 21, Figs O–Q)

Dimensions: Equatorial diameter 28 µm (1 specimen)

Remarks: Proteacidites cf. *stippulatus* shares the granulate sexine of *P. stippulatus* Stover and Partridge (1982). It most closely resembles the convex paratype (Plate 24, Figure 3 a, b), but possesses a thinner exine with a thicker sexine than nexine.

Botanical affinity: Proteaceae

Proteacidites subscabratus Couper 1960 (Plate 20, Fig. R)

Dimensions: Equatorial diameter 13 (18) 24 µm (7 specimens)

Age range: Middle to late Palaeocene in the Otway Basin (Harris 1971) and late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: Proteaceae, *Petrophile* (Milne and Martin 1998)

Proteacidites symphyonemoides Cookson 1950 (Plate 21, Figs A, B)

Dimensions: 22, 23 µm (2 specimens)

Remarks: The muri of specimens of *Proteacidites symphyonemoides* in the Mulga Rock palynoflora possess slightly thicker muri than those described by Stover and Partridge (1973). No measurements were given by Cookson (1950) and the figured specimen appears to be photographed at median focus and the muri and lumina are indistinct.

Age range: Middle to upper Miocene in the Gippsland Basin (Stover and Partridge 1973); upper Oligocene to middle Miocene in the Murray Basin (Macphail 1999); and, middle to late Eocene in the Otway Basin (Harris 1971). In WA, late Eocene at Zanthus (Milne 1988) and early Pliocene at Lake Tay (Bint 1981).

Botanical affinity: Proteaceae, *Symphionema* (Macphail 1999)

Proteacidites* cf. *symphyonemoides Cookson 1950 (not illustrated)

Dimensions: Equatorial diameter 22 (28) 33 µm (3 specimens)

Remarks: Proteacidites cf. *symphyonemoides* differs from *P. symphyonemoides* in that it possesses a finer meshed reticulum.

Botanical affinity: Proteaceae, possibly *Symphionema*

Proteacidites tenuiexinus Stover 1973 (Plate 21, Figs C–E)

Dimensions: Equatorial diameter 21 µm (1 specimen)

Age range: Palaeocene through late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); upper Oligocene to upper early Miocene in the Murray Basin (Macphail 1999); middle to late Eocene in the Werillup Formation of the former Bremer Basin (Stover and Partridge 1982) and late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: Proteaceae

Proteacidites tuberculatus Cookson 1950 (Plate 21, Figs F–H)

Dimensions: Equatorial diameter 44 µm (1 specimen)

Age range: Early Oligocene to upper Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and upper Eocene to middle Miocene in the Murray Basin (Macphail 1999). Not previously recorded in southern Western Australia.

Botanical affinity: Proteaceae

Proteacidites tuberculiformis Harris 1965 (Plate 21, Figs I, J)

Dimensions: Equatorial diameter 48 (60) 64 µm (6 specimens)

Remarks: Specimens of *Proteacidites tuberculiformis* in the Mulga Rock palynoflora are significantly smaller with slightly smaller verrucae than those described by Harris (1965) and the exine is mostly scabrate. The verrucae appear weakly attached as a few specimens only retain 2–8. .

Age range: Early to late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006) and Palaeocene in the Otway Basin (Harris 1971). Not previously recorded in southern WA.

Botanical affinity: Proteaceae (Macphail 1999)

Genus: *Santalumidites* (Cookson and Pike) Partridge 1973

Type species: *Santalumidites cainozoicus* (Cookson and Pike) Partridge 1973

Santalumidites cainozoicus Cookson and Pike 1954 (Plate 14, Figs E–H)

Dimensions: Length 20 (27) 32 µm, width 13 (18) 23 (49 specimens)

Remarks: The specimens of *Santalumidites cainozoicus* in the Mulga Rock palynoflora show a similar variation to that figured by Cookson and Pike (1954), who suggested

that their species may represent several species but that they possessed too few specimens to determine this. A significant number of specimens were recorded at Mulga Rock, but further research into differing characteristics of extant species is required before the number of species represented can be determined.

Age range: Early to late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006), upper Eocene to lowermost Oligocene in the Murray Basin (Macphail 1999); middle to late Eocene in WA (Stover and Partridge 1973, Milne 1988).

Botanical affinity: Santalaceae, *Santalum* (Macphail 1999)

Genus: *Triporopollenites* Pflug and Thomson 1953

Type species: *Triporopollenites coryloides* Pflug and Thomson 1953

Triporopollenites ambiguus Stover in Stover and Partridge 1973 (Plate 21, Figs K, L)

Dimensions: Equatorial diameter 26 (30) 43 µm (11 specimens)

Remarks: Stover and Partridge (1973) described the apiculae on specimens of *Triporopollenites ambiguus* in the Gippsland Basin as being widely scattered. This is true for the Mulga Rock specimens, but a range in size of the apiculae (0.5–1 µm) between grains was noted. For individual grains the size of the apiculae are consistent. Mulga Rock specimens of *T. ambiguus* also have a thinner exine, ranging from 0.5–0.75 µm thick.

Age range: Early to late Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); middle Eocene to early Pliocene in the Murray Basin (Macphail 1999); and middle to late Eocene in the Werillup Formation (Stover and Partridge 1982).

Botanical affinity: Proteaceae, *Telopea* (Macphail 1999)

Triporopollenites* cf. *ambiguus Stover and Partridge 1982 (not illustrated)

Dimensions: Equatorial diameter 35 µm (1 specimen)

Remarks: Triporopollenites cf. *ambiguus* possesses a thicker, differentiated exine and closer spaced apiculae than *T. ambiguus*.

Botanical affinity: Proteaceae, possibly *Telopea*

Triporopollenites delicatus Stover and Partridge 1982 (Plate 21, Figs M, N)

Dimensions: Equatorial diameter 30 µm (1 specimen)

Age range: Upper Eocene to middle Miocene in the Murray Basin (Macphail 1999). Recorded from the middle to late Eocene in the former Bremer Basin (Stover and Partridge 1982) and at Zanthus in the western Eucla Basin (Milne 1988).

Botanical affinity: Proteaceae, *Lomatia* (Macphail 1999)

Triporopollenites gemmatus Harris 1972 (not illustrated)

Dimensions: Equatorial diameter 26 µm individual, 30 µm tetrad (2 specimens)

Age range: Middle to late Eocene in the Otway Basin (Harris 1971, 1972). Present in the Werillup Formation in the Lefroy Palaeochannel, WA (Hos 1975).

Botanical affinity: Proteaceae

Triporopollenites vargus Stover and Partridge 1982 (Plate 21, Figs O–Q)

Dimensions: Equatorial diameter 37µm (1 specimen)

Age range: Middle to late Eocene in the former Bremer Basin (Stover and Partridge 1982). Late Eocene at Zanthus in the western Eucla Basin (Milne 1988).

Botanical affinity: Proteaceae

Triporopollenites* cf. *vargus Stover and Partridge 1982 (not illustrated)

Dimensions: Equatorial diameter 42 µm (1 specimen)

Remarks: Triporopollenites cf. *vargus* differs from *T. vargus* in that it possesses thinner muri.

Botanical affinity: Proteaceae

5.3.11 Stephanoporate pollen

Genus: *Malvacipollis* Harris 1965

Type species: *Malvacipollis diversus* Harris 1965

Malvacipollis diversus Harris 1965 (Plate 22, Figs A–C)

Dimensions: Equatorial diameter 17 (22) 29 µm (13 specimens)

Remarks: Malvacipollis diversus in the Mulga Rock palynoflora closely resembles those described by Stover and Partridge (1973), and are separated from *M. subtilis* in that they possess shorter and wider spines.

Age range: Upper Palaeocene to mid-middle Eocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); middle Eocene to upper Eocene in the Murray Basin (Macphail 1999); late Palaeocene to late Eocene in the Otway Basin (Harris 1971); middle to late Eocene in the former Bremer Basin (Stover and Partridge 1982); and late Eocene at Zanthus (Milne 1988) and in the Lefroy Palaeovalley (Hos 1975).

Botanical affinity: Euphorbiaceae, *Austrobuxus* (Macphail 1999)

Malvacipollis spinyspora (Martin) Mildenhall and Pocknall 1989 (Plate 23, Figs D, E)

Dimensions: 22 µm (1 specimen)

Age range: Upper Eocene to Pleistocene in the Murray Basin (Macphail 1999). Not previously recorded in WA.

Botanical affinity: Euphorbiaceae, *Micrantheum* (Macphail 1999), *Neoroepera*

Malvacipollis subtilis Stover in Stover and Partridge 1973 (Plate 22, Figs F, G)

Dimensions: Equatorial diameter 19 (23) 26 µm (11 specimens)

Remarks: Specimens assigned to *Malvacipollis* in the Mulga Rock palynoflora show two distinct populations; types possessing short and wide spinae and those with short and thin spinae. The pollen grains with short and thin spinae are here assigned to *M. subtilis* to keep them distinct from other forms. Unlike those described by Stover and Partridge (1973) specimens of *M. subtilis* are of similar size to *M. diversus*.

Age range: Upper Palaeocene through the mid-late Miocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); middle Eocene to lower Pliocene in the Murray Basin (Macphail 1999); middle to late Eocene in the former Bremer Basin (Stover and Partridge 1982) and late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: Euphorbiaceae, *Austrobuxus* (Macphail 1999)

5.3.12 Periporate pollen

Genus: *Periporopollenites* Pflug and Thomson 1953

Type species: *Periporopollenites stigmosus* Pflug and Thomson 1953

Periporopollenites demarcatus Stover in Stover and Partridge 1973 (Plate 22, Figs H–K)

Dimensions: Equatorial diameter 15 (21) 28 µm (35 specimens)

Age range: Early Eocene to early Oligocene in the Gippsland Basin (Stover and Partridge 1973, Partridge 2006); middle Eocene to upper early Miocene (Macphail 1999); middle to late Eocene in the Werillup Formation, former Bremer Basin (Stover and Partridge 1982); and late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: Trimeniaceae (Macphail 1999)

5.3.13 Pollen retained in tetrad

Genus: *Ericipites* Wodehouse 1933

Type species: *Ericipites longisulcatus* Wodehouse 1933

Ericipites scabratus Harris 1965 (Plate 22, Figs L–O)

Dimensions: Tetrad diameter 20 (25) 30 µm, diameter of individual grains 10 (15) 19 µm (31 specimens)

Age range: Middle Eocene to Pleistocene in the Murray Basin (Macphail 1999). Late Eocene at Zanthus, WA (Milne 1988).

Botanical affinity: Ericales; *Epacridaceae*, *Ericacea* (Macphail 1999)

6. Systematics of undescribed species

A total of 36 new species have been identified in this study; 16 are here described in detail and the remainder are noted with brief remarks. A further two species are described in Chapter 9, as they are included within a publication. The terminology used to describe each species was adopted from Punt *et al.* (2007). All species are illustrated in Appendix 6B (Plates 24–30). Those that are described with less than 10 specimens may not reflect total range of variation in those forms, but for the purpose of this study a name and description were deemed necessary to ensure later recognition of these species.

6.1 Cryptogam spores

Genus: Cyathidites Couper 1953

Type species: *Cyathidites australis* Couper 1953

***Cyathidites* sp**. (Plate 23, Figs A–C)

Dimensions: Equatorial diameter 30 (30) 32 µm (3 specimens)

Remarks: Cyathidites sp. possesses laesurae, general amb shape and exine similar to that of *C. australis/minor*, but differs in that it possesses a thick perine with a finely rugulate surface on the distal side of the spore, and interradial thickening. The spores of the extant *Cyathea cooperi* (W. J. Hooker ex F. von Mueller) Domin, 1929, the common tree fern, have a similar perine (Milne pers. comm.). Palynological preparations of *C. cooperi* spores contain specimens with and without the perine.

Botanical affinity: Possibly Cyatheaceae.

Genus: *Rugulatisporites* Thomson and Pflug 1953

Type species: *Rugulatisporites mallatus* Stover in Stover and Partridge 1973

***Rugulatisporites* sp**. (Plate 23, Fig. D)

Dimensions: Equatorial diameter 45 µm (1 specimen)

Remarks: Rugulatisporites sp. most closely resembles *R. micraulaxis* Partridge in Stover and Partridge 1973 but possesses a significantly thinner exine.

Botanical affinity: Likely Thyrsopteridaceae, similar to *R. micraulaxis.*

Spore sp. A (Plate 23, Fig. E)

Dimensions: 42 µm long, 23 µm wide (1 specimen)

Remarks: Spore sp. 14 most closely resembles *Laevigatosporites ovatus* Wilson and Webster 1946 but possesses small echinae, approximately 0.5 µm at the base and 0.5 µm high whereas *L. ovatus* has a psilate exine.

Botanical affinity: unknown.

Spore sp. B (Plate 23, Fig. F)

Dimensions: Equatorial diameter 28 (35) 36 µm (6 specimens)

Remarks: No other trilete spore species described for the Cenozoic or Cretaceous of Australia possesses a similar exoexine to Spore sp. B.

Botanical affinity: unknown.

6.2 Angiosperm pollen

6.2.1 Tricolpate pollen

Genus: Tricolpites Cookson ex Couper 1953

Type species: *Tricolpites reticulatus* Cookson ex Couper 1953

Tricolpites discoides sp. nov. (Plate 23, Figs G–I)

Description: Pollen tricolpate, isopolar, oblate; amb circular, always in polar view. Apertures gaping, 6–10 µm wide at equator, extend halfway to poles; colpi ends pointed, edges sharp. Exine 1.5–2 µm thick, indistinctly stratified; nexine slightly thinner to twice the sexine, thins towards apertures, infratectum thin. Sexine uniformly scabrate.

Etymology: Tricolpites discoides was named for the consistently circular shape of the amb.

Dimensions: Equatorial diameter 25 (33.5) 38 µm (6 specimens)

Holotype (Plate 23, Figs G–H)*:* Pollen tricolpate, isopolar, oblate; amb circular, polar view. Apertures gaping, 6–7 µm wide at equator, extend halfway to poles; colpi ends

pointed, edges sharp. Exine 1.75 µm thick, indistinctly stratified; nexine 0.75 µm, thins towards apertures, infratectum thin. Sexine 1 µm thick, uniformly scabrate.

Remarks: Tricolpites discoides differs from *Tricolpites discus* Harris in Kemp and Harris 1977, in that it is slightly larger, scabrate rather than tectate-perforate and possesses sharp colpi edges rather than ragged.

Botanical affinity: unknown angiosperm.

Tricolpites occultum sp. nov. (Plate 23, Figs J–M)

Description: Pollen tricolpate, isopolar, prolate; amb oval, equatorial view. Colpi simple, extending most of the length of the grain, often obscured in exine. Exine stratification distinct, exine 1–1.25 µm thick. Nexine thinner than sexine, 0.3–0.5 µm. Sexine 0.6–0.75 µm, finely reticulate, muri of equal width to lumina, lumina circular, 0.3–0.5 µm in diameter, fining to apertures.

Etymology: Tricolpites occultum was named for the often obscured colpi, with *occultum* being Latin for 'hidden'.

Dimensions: Equatorial diameter 19 (23) 26 µm, polar diameter 12 (13) 15 µm (13 specimens)

Holotype (Plate 23, Figs J–L)*:* Pollen tricolpate, isopolar, prolate; amb oval, always in equatorial view. Colpi simple, extending most of the length of the grain, often obscured in exine. Exine stratification distinct, exine 1 µm thick. Nexine thinner than sexine, 0.3 µm. Sexine 0.7 µm, finely reticulate, muri of equal width to lumina, lumina circular, 0.5 µm in diameter, fining to 0.3 µm at the apertures.

Remarks: Tricolpites occultum resembles *T. psilatus* Martin 1973 but is larger and reticulate, rather than psilate to finely granular.

Botanical affinity: unknown angiosperm.

Tricolpites reticuloides sp. nov. (Plate 23, Figs N–R)

Description: Pollen tricolpate, isopolar, oblate; amb circular to subcircular, always in polar view. Apertures gaping, 3–15 µm wide at equator; colpi ends pointed, edges sharp. Exine distinctly to indistinctly stratified, 0.75–1 µm thick, incurved at apertures. Nexine slightly thinner than or approximately equal to sexine. Sexine reticulate to per-reticulate, muri approximately equal to lumina, 0.5–1 µm in diameter, psilate at aperture margins.

Etymology: Named for the reticulate sculpture.

Dimensions: Equatorial diameter 22 (25) 31 µm (11 specimens)

Holotype (Plate 23, Figs N, O)*:* Pollen tricolpate, isopolar, oblate; amb circular, polar view. Apertures gaping, 3–6 µm wide at the equator, colpi ends pointed, edges sharp. Exine distinctly stratified, 1 µm thick. Nexine 0.25 µm, significantly thinner than the sexine. Sexine 0.75 µm; reticulate, muri equal to lumina, lumina 0.5 µm in diameter.

Paratype (Plate 24, Figs Q, R)*:* Pollen tricolpate, isopolar, oblate; amb circular, polar view. Apertures gaping, 10–11 µm wide at the equator, colpi ends pointed, edges sharp. Exine distinctly stratified, 1 µm thick. Nexine 0.5 µm, significantly thinner than the sexine. Sexine 0.5 µm; reticulate, muri 0.5 µm wide, lumina 0.5–1 µm in diameter.

Remarks: Tricolpites reticularis possesses a finer reticulum than described for other reticulate tricolpate species such as *T. incisus* Stover in Stover and Partridge 1973.

Botanical affinity: unknown angiosperm.

***Tricolpites* sp. A** (Plate 24, Figs A, B)

Dimensions: Equatorial diameter 25 (28) 33 µm (3 specimens)

Remarks: Tricolpites sp. A most resembles *T. discoides* sp. nov., but possesses a thicker sexine and a fine reticulum. It is differentiated from *T. discus* by an exine of consistent thickness across the grain.

Botanical affinity: unknown angiosperm.

***Tricolpites* sp. B** (Plate 24, Figs C, D)

Dimensions: Polar diameter 47 µm (1 specimen)

Remarks: The exine surface of *Tricolpites* sp. B is made up of closely spaced echinae. No other tricolpate pollen of similar size, with a similar echinate sculpture has been described from the Cenozoic in Australia or New Zealand.

Botanical affinity: unknown angiosperm.

6.2.2 Tricolporate Pollen

Genus: Rhoipites Wodehouse 1933

Type species: *Rhoipites bradleyi* Wodehouse 1933

Rhoipites oralongii sp. nov. (Plate 24, Figs E–G)

Description: Pollen tricolporate, subprolate to perprolate; amb rounded oval in equatorial view. Colpi distinct, flaring to poles, margins sharp. Pore lalongate in polar axis, don't extend past colpi externally, often indistinct. Exine 1-1.5 µm thick, thickening to the pole; nexine half thickness of sexine. Sexine thickens slightly at pole; reticulate, luminae 0.25-0.5 µm wide, muri approximately 0.25 µm wide.

Etymology: Named for the lalongate ora (pores).

Dimensions: Polar diameter 14 (19) 23 µm, equatorial diameter 10 (11.5) 13 µm (10 specimens)

Holotype (Plate 24, Figs E–G)*:* Pollen tricolporate, perprolate; amb rounded oval in equatorial view. Colpi distinct, flaring to poles, margins sharp. Ora lalongate in polar axis, 3 µm long, 1 µm wide, don't extend past colpi externally. Exine 1 µm thick at the pole, 0.8 µm at the equator; nexine less than 0.3 µm. Sexine approximately 0.5 µm, thickening at pole; reticulate, luminae 0.3 µm, muri approximately 0.25 µm wide.

Remarks: Rhoipites oralongii resembles *Rhoipites hawkdunensis* Mildenhall and Pocknall 1989 but differs in that the ora are exclusively lalongate and significantly longer in the polar axis without extending past the colpi. It is also similar to *Tricolpites retiformis* Martin 1973 but is tricolporate rather than tricolpate. *Rhoipites oralongii* differs from *R. orbiculatus* in that it possesses a lalongate rather than circular ora and a peroblate amb.

Botanical affinity: unknown angiosperm.

Rhoipites orbiculatus sp. nov. (Plate 24, Figs H–N)

Description: Pollen tricolporate, spheroidal; amb circular in equatorial view. Colpi distinct, extending to poles, flaring slightly to poles, margins sharp. Ora circular, 1–2 µm in diameter. Exine 0.8–1 µm thick; sexine approximately 0.7 µm, much thicker than indistinct nexine. Sexine of uniform thickness except for slight thickening at pole. Surface microreticulate, muri approximately equal to, or half, the diameter of the lumina, lumina less than 0.5 µm in diameter.

Etymology: Named for the spheroidal shape of the amb and the circular ora.

Dimensions: Polar diameter 13 (15) 19 µm, equatorial diameter 11 (14) 16 µm (14 specimens)

Holotype (Plate 24, Figs H–K)*:* Pollen tricolporate, spheroidal; amb circular in equatorial view. Colpi distinct, extending to poles, flaring slightly to poles, margins sharp. Ora circular, 1.75 µm in diameter. Exine 0.75 µm thick; nexine 0.15 µm, significantly thinner than sexine. Sexine approximately 0.6 µm. Surface microreticulate, muri approximately equal to, or half, the diameter of the lumina, lumina 0.3 µm.

Paratype (Plate 24, Figs L–N)*:* Pollen tricolporate, spheroidal; amb circular in equatorial view. Colpi distinct, extending to poles, flaring slightly to poles, margins sharp. Ora circular, 1.75 µm in diameter. Exine 1 µm thick; nexine 0.3 µm, much thinner than sexine. Sexine thickening slightly at pole. Surface microreticulate, muri approximately equal to, or half, the diameter of the lumina, lumina less than 0.3–0.5 µm.

Remarks: Rhoipites orbiculatus most closely resembles *Rhoipites rotundiformis* Truswell and Owen (1988) but differs in possessing a circular ora and a significantly thinner exine, with the sexine of greater thickness when compared to the nexine. The spheroidal amb, circular ora and distinct colpi distinguish *Rhoipites orbiculatus* from other small *Rhoipites* pollen of Cenozoic age described elsewhere in Australia.

Botanical affinity: unknown angiosperm.

***Rhoipites* sp. A** (Plate 24, Figs R–U)

Dimensions: Polar diameter 20 (21) 23 µm, equatorial diameter 18 (19) 24 µm (3 specimens)

Remarks: Rhoipites sp. A has a similar amb shape and exine structure to *Rhoipites rotundiformis* Truswell and Owen (1988). It differs in that it possesses a circular, rather than lalongate ora. It may still be conspecific, as the frequently distorted nature of specimens from Bungonia (Truswell and Owen 1988) makes this difficult to ascertain. It also resembles more ovoid specimens of *Rhoipites alveolatus* but lacks the thickening of the nexine to form a margin to the ora.

Botanical affinity: unknown angiosperm.

Genus: *Tricolporites* Cookson 1947

Type species: *Tricolporites sphaerica* Cookson 1947

***Tricolporites* sp. A** (Plate 24, Figs V–X)

Dimensions: Polar diameter 26, 30 µm, equatorial diameter 17, 19 µm (2 specimens)

Remarks: Tricolporites sp. A resembles *Ailanthipites paenestriatus* but differs in that the sculpture is made up of sparsely distributed perforations that do not form a reticulum. The colpi of *Tricolporites* sp. A also differ as they narrow at the equator and flare towards the poles.

Botanical affinity: unknown angiosperm.

***Tricolporites* sp. B** (Plate 24, Figs O–Q)

Dimensions: Polar diameter 18 µm (1 specimen)

Remarks: Tricolporites sp. B resembles *T.* cf. *isoreticulatus* (Kemp and Harris 1977) Macphail and Truswell 1993 in that the nexine protrudes at the pores, but differs in that it is microreticulate and significantly smaller.

Botanical affinity: unknown angiosperm.

6.2.3 Syncolporate Pollen

Genus: Myrtaceidites (Cookson and Pike) emend. Potonié 1960

Type species: *Myrtaceidites mesonesus* (Cookson and Pike) emend. Potonié 1960

Myrtaceidites corymbioides sp. nov. (Plate 24, Figs Y, Z)

Myrtaceidites sp. (Fig. 3P Mack and Milne 2015)

Description: Pollen syncolporate to parasyncolporate with arcuate colpi, isopolar, oblate; amb subtriangular to subcircular, sides strongly convex, apices rounded. Apertures circular, 1–3 µm in diameter, margins entire. Polar island absent to 2 µm in diameter. Exine indistinctly stratified, 0.75–2 µm thick mesoporially, 1.5–2.75 µm at the aperture. Nexine thicker than sexine, thickening to the aperture. Sexine consistent across grain, finely scabrate to psilate.

Etymology: Named for the resemblance of *Myrtaceidites corymbioides* to pollen produced by extant *Corymbia* K. D. Hill and L. A. S. Johnson.

Dimensions: Equatorial diameter 18 (23) 25 µm (14 specimens)

Holotype (Plate 24, Figs U, V)*:* Pollen syncolporate, isopolar, oblate; amb subcircular, sides strongly convex, apices rounded. Apertures circular, 1 µm in diameter, margins entire. Polar island absent. Exine indistinctly stratified, 1 µm mesoporially, 1.75 µm

at the aperture. Nexine thicker than sexine, thickening to the aperture. Sexine consistent across grain, psilate.

Remarks: Myrtaceidites corymbioides most closely resembles *M. eucalyptoides* forma *convexus* (Cookson and Pike) Martin 1973, but possesses a thicker exine and a psilate sculpture. Martin (1973) emended *M. eucalyptoides* f. *convexus* to include grains that lacked a thickening of the exine to the apertures. All specimens of *M. corymbioides* possess a thickened nexine at the aperture. Macphail and Thornhill (2012) appear to combine *M. eucalyptoides* f. *convexus* into *M. eucalyptoides* but the two have distinctly different amb shapes. The broadly rounded, almost circular, amb shape of *Myrtaceidites corymbioides* also separates it from *M. eucalyptoides*, as does the significantly larger size. *Myrtaceidites eucalyptoides* reaches only a maximum size of 18 µm in the Mulga Rocks palynoflora.

Botanical affinity: Myrtaceae, possibly *Corymbia.*

6.2.4 Triporate pollen

Genus: *Proteacidites* Cookson ex Couper 1953

Type species: *Proteacidites adenanthoides* Cookson 1950, by subsequent designation of Couper (1953)

Proteacidites ambassadatus sp. nov. (Plate 25, Figs A–F)

Description: Pollen triporate, isopolar with a slight polar protuberance on both sides, peroblate; amb triangular, sides straight to concave, apices truncated to slightly rounded. Apertures circular to lalongate, 2–4.5 µm in diameter. Exine 1.5–3 µm thick mesoporially, 1.5–2.5 µm at the apertures, distinctly stratified. Nexine 1–1.75 µm, thickening mesoporially, roughly twice as thick as sexine; annulate thinning occurs as an abrupt indentation in nexine before aperture, after which it thickens to apertures. Sexine 0.5–0.75 µm, thicker mesoporially, per-reticulate to finely reticulate, muri approximately equal to lumina, 0.3 µm wide.

Etymology: Named for the Ambassador uranium deposit at Mulga Rocks.

Dimensions: Equatorial diameter 28 (30) 38 (17 specimens)

Holotype (Plate 25, Figs A–C)*:* Pollen triporate, isopolar with a polar protuberance on both sides, peroblate; amb triangular, sides straight, apices truncated. Apertures

slightly lalongate, 3 µm in diameter. Exine 2.25 µm thick mesoporially, 2 µm at the apertures, distinctly stratified. Nexine 1.5 µm, thickening mesoporially, roughly twice as thick as sexine; annulate thinning occurs as an abrupt indentation in nexine after which nexine thickens to apertures. Sexine 0.5–0.75 µm, thicker mesoporially with 0.7 µm infratectum and 0.3 µm tectum, thinner and indistinctly stratified at the aperture; per-reticulate to finely reticulate, muri approximately equal to lumina, 0.3 µm wide.

Paratype (Plate 25, Figs D–F)*:* Pollen triporate, isopolar with a polar protuberance on both sides, peroblate; amb triangular, sides gently concave, apices slightly rounded. Apertures circular, 4 µm in diameter. Exine 2 µm thick mesoporially, 2 µm at the apertures, distinctly stratified. Nexine 1.5 µm, slightly thicker mesoporially, roughly twice as thick as sexine; annulate thinning occurs as an abrupt indentation in nexine before aperture, after which it thickens to apertures. Sexine 0.5–0.75 µm, thicker mesoporially but undifferentiated, thinner and indistinctly stratified at the aperture; per-reticulate to finely reticulate, muri approximately equal to lumina, 0.3 µm wide.

Remarks: Proteacidites ambassadatus is similar to *P. rynthius* Stover and Partridge 1982, but is distinguished by mesoporial thickening and annulate thinning of the nexine. The sexine of *Proteacidites ambassadatus* is also finely reticulate compared to the small reticulum of *P. rynthius*. The exine in *P. bremerensis* Stover and Partridge 1982 also thickens mesoporially, but more significantly than in *P. ambassadatus* sp. nov. *Proteacidites reflexus* Partridge in Stover and Partridge 1973 also has a thicker mesoporial nexine, but the exine as a whole thins significantly to the apertures.

Botanical affinity: Proteaceae.

Proteacidites colubrimodus sp. nov. (Plate 25, Figs G–L and Plate 26, Figs A–C)

Description: Pollen triporate, occasionally with four pores, anisopolar with one side more convex than the other, suboblate; amb triangular, sides straight to slightly convex, apices truncated. Apertures circular, 3.5–7 µm in diameter, margins entire. Exine distinctly stratified, 2–4 µm thick. Nexine 0.75–1.75 µm, thinner to approximately equal to the sexine. Sexine 1.5–2.25 µm, with large infratectum 0.75–1 µm, tectum 1–1.25 µm, weakly attached; reticulate with 0.75–2 µm diameter circular to polygonal lumina, size and shape consistent within individual grains;

intraluminal, 0.3 µm diameter granae observable at margins of lumina, muri 0.75–1.25 µm thick.

Etymology: Proteacidites colubrimodus is named for the Latin for ‘snakelike’, due to its easily shed exine and the almost scaly appearance of the sculpture.

Dimensions: Equatorial diameter 36 (39.5) 53 µm (6 specimens)

Holotype (Plate 25, Figs G–I)*:* Pollen triporate, anisopolar with one side more convex than the other, suboblate; amb triangular, sides slightly convex, apices truncated. Apertures circular, 4 µm in diameter, margins entire. Exine distinctly stratified, 2.75 µm thick. Nexine 0.75 µm, thinner than sexine. Sexine 2 µm, with large infratectum 1 µm, tectum 1 µm, weakly attached; reticulate with 1–2 µm polygonal lumina, size and shape consistent; intraluminal, 0.3 µm diameter granae observable at margins of lumina, muri 1–1.25 µm wide.

Paratype (Plate 25, Figs J–L)*:* Pollen triporate, anisopolar with one side more convex than the other, suboblate; amb triangular, sides slightly convex, apices truncated. Apertures circular, 7 µm in diameter, margins entire. Exine distinctly stratified, 3 µm thick Nexine 1 µm, thinner than sexine. Sexine 2 µm, infratectum 0.75 µm, tectum 1.25 µm, weakly attached; per-reticulate with 1–2 µm diameter polygonal lumina, size and shape consistent; intraluminal, 0.3 µm diameter granae observable at margins of lumina, muri 0.75–1.25 µm wide.

Remarks: Proteacidites colubrimodus differs from all other *Proteacidites* spp. described in that it possesses a very distinctive sculpture. *Propylipollis robustus* Dudgeon 1983 is similarly per-reticulate, but with significantly smaller lumina.

Botanical affinity: Proteaceae.

Proteacidites crochetaria sp. nov. (Plate 26, Figs D–G)

Description: Pollen triporate, isopolar, oblate; amb triangular, sides convex, apices rounded. Apertures circular, 4.5–5 µm in diameter, margins entire. Exine distinctly stratified, 2.75–4 µm thick. Nexine 0.75–1.25 µm, significantly thinner than sexine. Sexine 2–2.75 µm with distinct infratectum and tectum, 0.5–1 µm and 1.25–2.25 µm respectively; reticulate with 1.25–2.5 µm wide muri enclosing polygonal lumina 1.5–5 µm in diameter. Duplicollumellate predominately along both margins of muri, collumellae 0.3 µm in diameter, occasionally fused mid-muri and approximately 1 µm in diameter; expressed as supratectal granae.

Etymology: Named for the resemblance of the sculpture to crochet patterning.

Dimensions: Equatorial diameter 28 (31) 36 µm (13 specimens)

Holotype (Plate 26, Figs D–G)*:* Pollen triporate, isopolar, oblate; amb triangular, sides convex, apices rounded. Apertures circular, 4.5 µm in diameter, margins entire. Exine distinctly stratified, 3 µm thick. Nexine 0.75 µm, significantly thinner than sexine. Sexine 2.25 µm with distinct infratectum and tectum, 1 µm and 1.25 µm respectively; reticulate with 1.5–2.5 µm wide muri enclosing polygonal lumina 1.5–5 µm in diameter. Duplicollumellate predominately along both margins of muri, collumelae 0.3 µm in diameter, occasionally fused mid-muri and approximately 1 µm in diameter; expressed as supratectal granae.

Remarks: Proteacidites crochetaria resembles *P. confragosus*, but is significantly smaller with a coarser reticulum. The collumelae in *P. confragosus* are significantly larger, of consistent size, as wide as the muri.

Botanical affinity: Proteaceae.

Proteacidites microspinosus sp. nov. (Plate 26, Figs H–L)

Description: Pollen triporate, isopolar to anisopolar, peroblate; amb triangular, sides straight to gently concave. Apertures circular to slightly lalongate, 2–4 µm in diameter. Exine 1.25–1.5 µm thick, thickening to 1.5–2 µm at apertures, often indistinctly stratified; nexine generally twice as thick as sexine, nexine thickening slightly at apertures. Sexine echinate, echinae 0.25–0.5 µm long, 0.5 µm wide at base, 1.5–3 µm apart on average, rarely as close as 0.5 µm.

Dimensions: Equatorial diameter 23 (26) 32 µm (15 specimens)

Etymology: Proteacidites microspinosus is named for the spines comprising the sculpture.

Holotype (Plate 26, Figs H–J)*:* Pollen triporate, isopolar, peroblate; amb triangular, sides straight. Apertures slightly lalongate, 4 µm in diameter. Exine 1.5 µm thick, thickening to 2 µm at the apertures, indistinctly stratified; nexine twice as thick as sexine, thickening at the aperture. Sexine echinate, echinae 0.5 µm long, 0.5 µm wide at base, 1.5–2.5 µm apart.

Paratype (Plate 26, Figs K, L)*:* Pollen triporate, anisopolar, peroblate; amb triangular, sides gently concave. Apertures circular, 2.5 µm in diameter. Exine 1.25 µm thick, thickening to 1.75 µm at the apertures, indistinctly stratified; nexine twice as thick as sexine, thickening at the apertures. Sexine echinate, echinae 0.5 µm long, 0.5 µm wide at base, 1.5–3 µm apart on average.

Remarks: Proteacidites microspinosus differs from *Triporopollenites ambiguus* Stover 1973 in that the grains are significantly smaller with smaller apertures. The thickening of the nexine at the aperture in *P. microspinosus* is also more significant than in *T. ambiguus.* Measurements of the exine weren't given in the original description (Stover and Partridge 1973), and it is possible that *P. microspinosus* is on a continuum with this species. *P. microspinosus* also resembles *Triporopollenites apiculatus* Stover and Partridge 1982 but differs in possessing smaller echinae, a thinner exine and a smaller size range.

Botanical affinity: Proteaceae.

Proteacidites narnooensis sp. nov. (Plate 26, Figs M–P)

Description: Pollen triporate, isopolar, peroblate; amb triangular, sides straight to gently concave. Apertures lalongate, margins entire, 1.5–4 µm in diameter. Exine distinctly stratified 1.25–2 µm thick mesoporially, thinning to 0.5–0.75 µm prior to the apertural collar before thickening to 1–1.75 µm at the apertures. Nexine 0.75–1.5 µm mesoporially, apertures encircled by band of disrupted nexine 2.5–3.5 µm from aperture margin, nexine irregularly striate within collar, thinning just prior to collar in some specimens. Sexine 0.5–0.75 µm, thickening mesoporially in some specimens, thinning slightly at aperture; finely granulate.

Etymology: Named for the map sheet within which the Mulga Rock deposits is located.

Dimensions: Equatorial diameter 14 (17) 25 µm (20 specimens)

Holotype (Plate 26, Figs M, N)*:* Pollen triporate, isopolar, peroblate; amb triangular, sides gently concave. Apertures lalongate, margins entire, 3 µm in diameter. Exine distinctly stratified 1.5 µm thick mesoporially, thinning to 0.75 µm prior to the apertural collar, before thickening to 1.25 µm at the apertures. Nexine 1 µm mesoporially, apertures encircled by band of disrupted nexine 3.5 µm from aperture margin, nexine irregularly striate within collar, thinning to 0.25 µm prior to collar. Sexine 0.5 µm, consistent across most of grain, thinning slightly at the aperture; finely granulate.

Paratype (Plate 26, Figs O, P)*:* Pollen triporate, isopolar, peroblate; amb triangular, sides gently concave. Apertures lalongate, margins entire, 3.5 µm in diameter. Exine distinctly stratified 2 µm thick mesoporially, thinning to 0.75 µm prior to the apertural collar, before thickening to 1.25 µm at the apertures. Nexine 1.25 µm mesoporially, apertures encircled by band of disrupted nexine 3.5 µm from aperture

margin, nexine irregularly striate within collar, absent prior to collar. Sexine 0.5 µm, consistent across most of grain, thinning slightly at the aperture; finely granulate.

Remarks: Proteacidites narnooensis possesses an aperture similar to that of *Proteacidites annularis* Cookson 1950, but differs in the thickening of the exine mesoporially. *Proteacidites narnooensis* resembles *P. reflexus* Partridge 1973 and *P. bremerensis* Stover and Partridge 1982 in that it thickens mesoporially but it is significantly smaller than both previously described species. The exine of *P. reflexus* is also distinct from *P. narnooensis* in that it thins abruptly to the apertures.

Botanical affinity: Proteaceae.

Proteacidites polygonalis sp. nov. (Plate 26, Figs Q–T)

Description: Pollen triporate, isopolar to slightly anisopolar, peroblate; amb triangular with rounded apices, angulaperturate, sides straight to gently concave. Apertures circular, 0.8–2.5 µm in diameter. Exine 0.5–1.25 µm thick, distinctly stratified. Nexine 0.4–0.75 µm, equal to or thinner than sexine; thinning to the apertures. Sexine 0.5–0.6 µm, finely reticulate, lumina polygonal, 0.5–1 µm in diameter, markedly reduced at the apertures. Muri ≤0.5 µm wide and tortuous, collumelae indistinct.

Etymology: Proteacidites polygonalis was named for the polygonal lumina.

Dimensions: Equatorial diameter 23 (25.5) 28 µm (6 specimens)

Holotype (Plate 26, Figs Q, R)*:* Pollen triporate, isopolar, peroblate; amb triangular, sides straight. Apertures circular, 0.8 µm in diameter. Exine 1.25 µm thick, distinctly stratified. Nexine 0.75 µm, equal to or thinner than sexine; almost absent at apertures. Sexine 0.5 µm, finely reticulate, lumina polygonal, mostly 0.5 µm in diameter, occasionally 0.75 µm, markedly reduced at the apertures. Muri ≤0.5 µm wide and tortuous, collumelae indistinct.

Paratype (Plate 26, Figs S, T)*:* Pollen triporate, isopolar, peroblate; amb triangular, sides straight. Apertures circular, 2.5 µm in diameter. Exine 1 µm thick, distinctly stratified. Nexine 0.4 µm, equal to or thinner than sexine; almost absent at apertures. Sexine 0.6 µm, finely reticulate, lumina polygonal, mostly 1 µm in diameter, occasionally smaller, markedly reduced at the apertures. Muri ≤0.5 µm wide and tortuous, collumelae indistinct.

Remarks: Proteacidites polygonalis is distinguishable from *P. adenanthoides* by the polygonal, rather than circular lumina. *Proteacidites polygonalis* is most similar to *P.*

pseudomoides Stover in Stover and Partridge 1973 and *P. symphyonemoides* Cookson 1950, but possesses a thinner exine than either. The meshed reticulum of *P. polygonalis* is significantly smaller than that seen in *P. symphyonemoides*. *Proteacidites polygonalis* also resembles *P. crassus* Cookson 1950, but possesses finer muri indistinct collumelae and a thinning of the exine towards the apertures which is not seen in *P. crassus*.

Botanical affinity: Proteaceae.

Proteacidites protrudens sp. nov. (Plate 27, Figs A–F)

Description: Pollen triporate, isopolar to anisopolar with inflated specimens more convex on one side, oblate; amb broadly triangular, sides gently convex to straight, apices truncated. Apertures protruding, circular, 3.5–5 µm in diameter, margins entire. Exine distinctly stratified, 1–1.5 µm thick mesoporially, thickening to 2.25–2.5 µm at the aperture. Nexine 0.5–1 µm thickening to 1.75–2 µm at the apertures; disrupted near aperture, appearing striate; twice as thick or approximately equal to sexine mesoporially. Sexine 0.25–0.5 µm, thinning slightly to the apertures in some grains; reticulate, muri 0.5–0.75 µm wide, lumina polygonal, 0.3–1 µm in diameter, consistent across grain.

Etymology: Named for the protruding apertures.

Dimensions: Equatorial diameter 27 (32) 41 µm (7 specimens)

Holotype (Plate 27, Figs A–C)*:* Pollen triporate, isopolar, oblate; amb broadly triangular, sides gently convex, apices truncated. Apertures protruding, circular, 4 µm in diameter, margins entire. Exine distinctly stratified, 1.5 µm thick mesoporially, thickening to 2.25 µm at the aperture. Nexine 1 µm, thickening to 1.75 µm at the apertures; disrupted through aperture, appearing striate; twice as thick or approximately equal to sexine mesoporially. Sexine 0.5 µm, thinning slightly to the apertures in some grains; reticulate, muri 0.75 µm wide, lumina polygonal, 0.3–1 µm in diameter, consistent across grain.

Paratype (Plate 27, Figs D–F)*:* Pollen triporate, isopolar, oblate; amb broadly triangular, sides straight, apices truncated. Apertures protruding, circular, 4.5 µm in diameter, margins entire. Exine distinctly stratified, 2 µm thick mesoporially, thickening to 2.75 µm at the aperture. Nexine 1.25 µm thickening to 2 µm at the apertures; disrupted through aperture, appearing striate; twice as thick or approximately equal to sexine mesoporially. Sexine 0.75 µm, thinning slightly to the

apertures in some grains; reticulate, muri 0.65 µm wide, lumina polygonal, 0.3–0.75 µm in diameter, consistent across grain.

Remarks: Proteacidites protrudens resembles *Propylipollis robustus* Dudgeon 1983, but possesses protruding apertures and a striate nexine at the aperture.

Botanical affinity: Proteaceae.

Proteacidites rickmanii sp. nov. (Plate 27, Figs G–J)

Description: Pollen triporate, anisopolar; amb triangular, apices truncated to slightly rounded, sides gently convex. Apertures protrusive, subcircular, 7–9 µm in diameter, margins entire. Exine distinctly stratified, 1.75–3 µm thick mesoporially, 2–2.5 µm at the aperture. Nexine 1–1.75 µm, thickening mesoporially and thinner prior to the aperture; band of thickened nexine surrounds margin of aperture, approximately 1 µm thick. Sexine 0.75–1.25 µm thick, thickening mesoporially; reticulate, muri 0.5–1 µm wide, simplibaculate, tortuous, enclosing lumina 0.5–2.5 µm in diameter, decreasing to 1 µm at the apertures.

Etymology: Named for the late actor, Alan Rickman.

Dimensions: Equatorial diameter 46 (52) 57 µm (8 specimens)

Holotype (Plate 27, Figs G–J)*:* Pollen triporate, anisopolar; amb triangular, apices truncated to slightly rounded, sides gently convex. Apertures protrusive, subcircular, 7 µm in diameter, margins entire. Exine distinctly stratified, 3 µm thick mesoporially, 2.5 µm at the aperture. Nexine 1.75 µm, thickening mesoporially and thinner prior to the aperture; band of thickened nexine surrounds aperture margin, approximately 1 µm thick. Sexine 0.75–1.25 µm, thickening and stratified mesoporially with infratectum and tectum 0.25 µm and 1 µm respectively; reticulate, muri 0.5 µm thick, simplibaculate, tortuous, enclosing lumina 0.5–2 µm in diameter, decreasing to 1 µm at the apertures.

Remarks: Proteacidites rickmanii most closely resembles *Proteacidites recavus* Stover in Stover and Partridge 1973 but possesses a thinner exine and thinner muri. It is also similar to *P. symphyonemoides* but is significantly larger. *Proteacidites angulatus* Stover in Stover and Partridge 1973 possesses a similar amb shape, but *P. rickmanii* is significantly larger. It is, however, much smaller than other large reticulate species such as *Proteacidites grandis* Cookson 1950 and *P. leightonii* Stover in Stover and Partridge 1973. The muri are most similar to those of *P. leightonii*, but the lumina of *P. rickmanii* are smaller in diameter.

Botanical affinity: Proteaceae.

Proteacidites tesselaria sp. nov. (Plate 28, Figs A–E)

Description: Pollen triporate, anisopolar, with one side more convex than the other; amb triangular, sides straight to concave, apices truncated. Apertures slightly protruding, circular, 2–3 µm in diameter, margins entire. Exine distinctly stratified, 1–1.25 µm thick, consistent across grain. Nexine 0.5–0.75 µm, equal to or thicker than the sexine. Sexine 0.3–0.5 µm; reticulate, consistent across grain with muri 0.3 µm wide enclosing polygonal lumina, 1–4 µm in diameter.

Etymology: Proteacidites tesselaria is named for the thin muri that create an illusion of closely fitted polygonal shapes.

Dimensions: Equatorial diameter 18 (19) 21 µm (11 specimens)

Holotype (Plate 28, Figs A–C)*:* Pollen triporate, anisopolar, with one side more convex than the other; amb triangular, sides straight, apices truncated. Apertures slightly protruding, circular, 3 µm in diameter, margins entire. Exine distinctly stratified, 1 µm thick, consistent across grain. Nexine 0.7 µm, equal to or thicker than the sexine. Sexine 0.3 µm; reticulate, consistent across grain with muri approximately 0.3 µm wide enclosing polygonal lumina, 1–4 µm in diameter.

Paratype (Plate 28, Figs D, E)*:* Pollen triporate, anisopolar, with one side more convex than the other; amb triangular, sides gently concave, apices truncated. Apertures slightly protruding, circular, 3 µm in diameter, margins entire. Exine distinctly stratified, 1 µm thick, consistent across grain. Nexine 0.5 µm, equal to or thicker than the sexine. Sexine 0.5 µm; reticulate, consistent across grain with muri 0.3 µm wide enclosing polygonal lumina, 1–3 µm in diameter.

Remarks: Several small reticulate species are described for Paleogene palynofloras (e.g. *P. pseudomoides*, *P. reticulatus,* and *P. symphyonemoides*). *Proteacidites tesselaria* is distinguished from them by distinctively fine muri and relatively large lumina.

Botanical affinity: Proteaceae.

Proteacidites vaga sp. nov. (Plate 28, Figs F–K)

Description: Pollen triporate, isopolar; amb triangular, sides straight to gently concave, apices truncated. Apertures lalongate, 4–6 µm in diameter, margins entire. Exine stratification distinct to indistinct, 1–1.75 µm thick mesoporially and at the apertures. Nexine 0.75–1 µm, thinning between the mesoporial region and the apertures. Sexine

0.25–0.75 µm, thickening mesoporially, thinning right at the apertural margin; sculpture very low relief, appearing per-reticulate to reticulate, with muri approximately equal in size to lumina, less than 0.5 µm; careful LO analysis reveals granula, 0.5–1.5 µm in diameter.

Etymology: Proteacidites vaga is named for the low relief granulate sculpture that is often unclear and appears finely reticulate.

Dimensions: Equatorial diameter 29 (34) 39 µm (38 specimens)

Holotype (Plate 28, Figs F–I)*:* Pollen triporate, isopolar; amb triangular, sides straight, apices truncated. Apertures lalongate, 6 µm in diameter, margins entire. Exine stratification indistinct, 1 µm thick mesoporially and at the apertures. Nexine 0.75 µm, thinning between the mesoporial region and the apertures. Sexine 0.25 µm, granulate with granula 0.5–1.5 µm in diameter.

Paratype (Plate 29, Figs J, K)*:* Pollen triporate, isopolar; amb triangular, sides straight to gently concave, apices truncated. Apertures lalongate, 5 µm in diameter, margins entire. Exine stratification distinct, 1.75 µm thick, mesoporially and at the apertures. Nexine 1 µm, thinning between the mesoporial region and the apertures. Sexine 0.75 µm, thickening mesoporially with distinct 0.5 µm infratectum and 0.25 µm tectum, thinning right at the apertural margin; sculpture very low relief, appearing per-reticulate with muri slightly thicker than lumina, less than 0.5 µm.

Remarks: Proteacidites vaga resembles *Proteacidites tenuiexinus* Stover and Partridge 1973, but *P. tenuiexinus* has a consistent, very low relief sculpture and a significantly thinner nexine. It also resembles *Proteacidites sinulatus* Dudgeon 1983 but lacks the mesoporial thickening of the nexine. The shape of the amb resembles *P. rynthius* but *P. vaga* possesses a granulate, rather than reticulate, sculpture.

Botanical affinity: Proteaceae.

***Proteacidites* sp. A** (Plate 28, Figs L, M)

Description: Pollen triporate, isopolar, oblate; amb broadly triangular with rounded apices, sides concave. Apertures lalongate with entire margins, 4 µm in diameter. Exine distinctly stratified, 1–1.25 µm thick, thickening to the apertures. Nexine 0.75–1 µm, thicker than sexine. Sexine approximately 0.5 µm, reticulate; muri 0.5 µm wide, forming polygonal lumina 0.5–1 µm in diameter.

Dimensions: Equatorial diameter 21 (26) 35 µm (3 specimens)

Remarks: Proteacidites sp. A resembles *P. cirritulus* Milne 1988 but possesses a coarser meshed reticulum and is larger in size. It also possesses similarities to *Propylipollis robustus* Dudgeon 1983, but has thinner muri. *Proteacidites* sp. A differs from *Triporopollenites delicatus* as the exine is thinner and thickens to the apertures.

Botanical affinity: Proteaceae.

***Proteacidites* sp. B** (Plate 28, Figs N, O)

Description: Pollen triporate, isopolar, oblate; amb broadly triangular with rounded apices. Apertures lalongate with entire margins, 3–4 µm in diameter. Exine distinctly stratified, 1–1.25 µm thick, consistent across grain. Nexine 0.75–1 µm, approximately twice the sexine. Sexine approximately 0.5 µm, perforate; perforations 0.3–0.5, 0.3 µm apart on average.

Dimensions: 19, 27 µm (2 specimens)

Remarks: Proteacidites sp B is distinguished from *Proteacidites* sp. A, by its perforate sculpture, .though it shares a similar amb shape and wall structure.

Botanical affinity: Proteaceae.

***Proteacidites* sp. C** (Plate 28, Figs P, Q)

Description: Pollen triporate, isopolar, oblate; amb triangular with truncated apertures. Pores circular 3–3.5 µm in diameter with entire margins. Exine 1 µm thick mesoporially, 0.5–0.75 µm at the apertures. Nexine approximately equal to the sexine, diminishing to apertures. Sexine consistent across grain, finely scabrate.

Dimensions: Equatorial diameter 17 (19) 26 µm (3 specimens)

Remarks: Proteacidites sp. 4 is most similar to *P. beddoesii* Stover in Stover and Partridge 1973, but lacks the elongate amb and apiculate sexine. It also resembles *P. tenuiexinus*, but is distinguished by the mesoporial thickening of the nexine.

Botanical affinity: Proteaceae.

***Proteacidites* sp. D** (Plate 28, Figs R, S)

Dimensions: Equatorial diameter 21 (22) 22 µm (5 specimens)

Remarks: Proteacidites sp. D resembles *Proteacidites reticulatus* Cookson 1950 but differs in that it possesses a much thicker exine, of which the nexine is a more

significant component. Circular lumina, up to 0.5 µm, occur within the muri similar to those described for *Tricolpites incisus*.

Botanical affinity: Proteaceae.

***Proteacidites* sp. E** (Plate 28, Figs T–W)

Description: Pollen triporate, isopolar, peroblate; amb triangular, sides convex, apices truncated. Apertures circular, 4.5 µm in diameter, margins entire. Exine distinctly stratified, 2.75–4 µm thick. Nexine 0.75–1 µm, significantly thinner than sexine. Sexine 2 µm; reticulate with 1.25 µm wide muri enclosing polygonal lumina 4.5–8 µm in diameter. Collumelae visible, 0.3–1 µm in diameter, underlying and outlining the muri.

Dimensions: Equatorial diameter 32 (34) 36 µm (3 specimens)

Remarks: Proteacidites sp. E differs from *P. crochetaria* sp. nov. in that it possesses larger muri, though this could be a result of the reticulum breaking. It also has a significantly thinner, indistinct, infratectum.

Botanical affinity: Proteaceae.

***Proteacidites* sp. F** (Plate 29, Figs A–C)

Dimensions: 30 µm (2 specimens)

Remarks: Proteacidites sp. F resembles *P. crassus* but has broadly rounded apices and thinner muri. Other *Proteacidites* species described from the Paleogene with rounded apices lack the concave sides.

Botanical affinity: Proteaceae.

***Proteacidites* sp. G** (Plate 29, Figs D–F)

Dimensions: 31, 39 µm (2 specimens)

Remarks: Proteacidites sp. G is similar to *P. confragosus* Harris 1972 but is significantly smaller with tortuous muri.

Botanical affinity: Proteaceae.

***Proteacidites* sp. H** (Plate 29, Figs G, H)

Dimensions: 48 µm (1 specimen)

Remarks: Proteacidites sp. H resembles *P. annularis* in that it possesses a disrupted nexine at the apertures that forms a striate collar, but differs in that it is significantly

larger and lacks the annulate thinning of the exine. The strongly truncated apertures of *P.* sp. H also resemble *P.* aff. *Isopogon*, but can be distinguished by the apertural collars.

Botanical affinity: Proteaceae.

***Proteacidites* sp. I** (Plate 29, Figs I–K)

Dimensions: 41, 60 µm (2 specimens)

Remarks: Proteacidites sp. I can be distinguished from similar proteaceous pollen described from the Cenozoic of Australia by possessing a distinct infratectum. It resembles *P. colubrimodus* sp nov. but the exine is significantly thinner relative to the size of the grain.

Botanical affinity: Proteaceae.

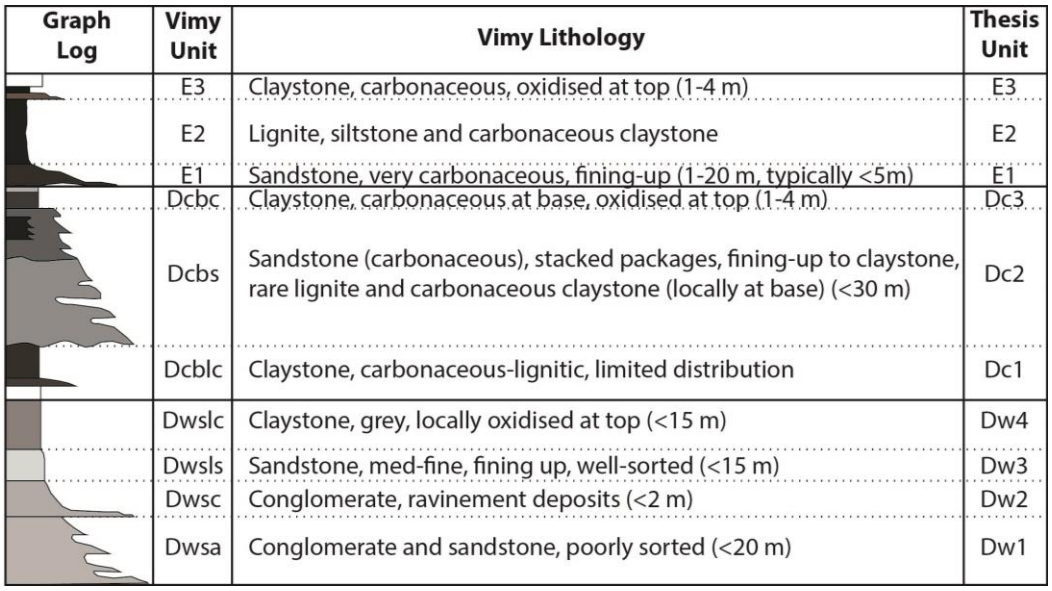
7. Results: lithostratigraphy and palynological distribution

The species identified in Chapters 5 and 6 have a varying distribution within the drill holes studied (Appendix 3). This chapter, using percent occurrences derived from a 200-grain count for each sample, will describe the distributions of both major pollen groups and individual species within the context of the lithostratigraphy (Fig. 7.1). Section 7.1 outlines the correlation of sedimentary units identified in each drill hole to Vimy Resources' composite stratigraphic scheme (Fig. 7.2) to provide a framework for the palynomorph trends. Diamond core and air core drill holes are described separately, as sampling differed between the two drilling methods (Chapter 4). Section 7.2 correlates major pollen group trends and distribution of individual species to the stratigraphic units.

7.1 Lithostratigraphic correlation of drill holes against Vimy Resources' stratigraphic scheme

Two previously completed lithostratigraphic divisions of the sedimentary infill at Mulga Rock are available for comparison; Douglas *et al.* (2011) and Fewster (1999). Douglas *et al.* (2011) referred to an upper clay rich interval and a lower sand in their study of the Ambassador deposit. This division is likely associated with the boundary between Units E1 and E2 in the Vimy Resources stratigraphy for the Mulga Rocks Project. This boundary is consistently present in all drill holes studied. The sub division of sediments by Vimy is more difficult to recognise, and the assignment of these in each drill hole is discussed below. The names of the units used by Vimy have been adjusted for this study (e.g. Dcblc to Dc1), to better reflect the order in which they were deposited (Fig. 7.1). This correlation is focussed on the Eocene D and E intervals, as underlying units are older than the scope of this study and overlying units are too heavily oxidised to preserve palynomorphs. There are some limitations with using the composite stratigraphic column outlined by Vimy (Figs 2.4 and 7.1). Many of the units have been simplified, such as clayey-sands and sandy-clays being logged as either pure sandstone or pure claystone, though the percentages of each may make this decision arbitrary. The colour changes represented in the Graph log of Vimy's stratigraphy (Fig. 7.1) are also not consistent across the cross

section. The lithostratigraphic correlation presented here (Fig. 7.2) has been drafted from raw log data, collected during drilling, that were provided by Vimy. Digitisations of the original logs are presented in Appendix 7. The diamond core drill holes and air core drill holes are discussed here separately.



Graph Log	Vimy Unit	Vimy Lithology	Thesis Unit
	E3	Claystone, carbonaceous, oxidised at top (1-4 m)	E3
	E2	Lignite, siltstone and carbonaceous claystone	E2
	E1	Sandstone, very carbonaceous, fining-up (1-20 m, typically <5m)	E1
	Dcbc	Claystone, carbonaceous at base, oxidised at top (1-4 m)	Dc3
	Dcbs	Sandstone (carbonaceous), stacked packages, fining-up to claystone, rare lignite and carbonaceous claystone (locally at base) (<30 m)	Dc2
	Dcblc	Claystone, carbonaceous-lignitic, limited distribution	Dc1
	Dwslc	Claystone, grey, locally oxidised at top (<15 m)	Dw4
	Dwsls	Sandstone, med-fine, fining up, well-sorted (<15 m)	Dw3
	Dwsc	Conglomerate, ravinement deposits (<2 m)	Dw2
	Dwsa	Conglomerate and sandstone, poorly sorted (<20 m)	Dw1

Fig. 7.1 Units E and D in the Vimy Resources Ltd stratigraphy for the Mulga Rock Project (adapted from Vimy Resources pers. comm.). Unit names under lithology are those used in this discussion.

7.1.1 Diamond drill holes (NND-5077, NND-5028, NND-5030, CD-1-779)

The finer scale logging of diamond drill holes studied here (Appendix 7), as opposed to that of the air core drill holes, has made correlation with Vimy's current generalised stratigraphic column for the Mulga Rock deposits difficult. The E interval units are easily recognised, in particular the lignites of E2. The boundary with the D interval is also easy to recognise, but the sub divisions of unit D are less clear. In many cases minor interbeds have been logged for the diamond cores that were not resolvable and likely grouped in logging of air core holes.

NND-5077: Vimy commenced coring in NND-5077 at 43 m, with the end of hole at 54 m from surface. The limited depth range means that only the lignitic unit E2, and the underlying carbonaceous sands of E1, are recognised for this drill hole. Most of the sediment is a dark brown to black lignite, with only 1.5 m of poorly sorted

carbonaceous sandstone present at the base of the hole. Only the lower section of the drill hole was available for sampling.

NND-5030: Coring commenced at 35 m below surface within the E2 interval. A small, 2 m interval of E1 carbonaceous sand is present. Unlike in NND-5077, units from the D interval were cored with the uppermost four sub-units recognised; Dc3, Dc2, Dw4 and Dw3 (as Dc1 is noted to be of limited distribution).

NND-5028: It was not possible to assign sediments to the E3 unit in this drill hole, with oxidised sands directly overlying the E2 lignite. Unit E1 in NND-5028 is highly carbonaceous and particularly coarse grained. An unusual interbed of lignite is also notable within the sands assigned to E1. It was particularly difficult to subdivide Unit D in NND-5028, as it is mostly sandy with only minor interbeds of more clay rich units. Unit Dc3 is likely present, but is only 30 cm thick and much thinner than the 1–4 m stated within Vimy's stratigraphy. Boundaries between the other sub units are difficult to ascertain, but divisions between Dc2, Dw4 and Dw3 have been tentatively placed. Dw4 is only present if it is a locally coarser bed and is recognised on the basis of the oxidation associated with the upper portion of the unit. It is possible that the sediments of Dw4 can instead be assigned to Dw3 in NND-5028. The end of hole is within unit Dw3.

CD-1-779: Unit E3 is present but appears more variable than represented in the air core holes logged by Vimy. The basal 2–3 m is distinguished by the preservation of worm burrows in lighter brown clay than the rest of the interval. Unit E2 is also more variable with small sandy interbeds within the lignite. The boundary between E2 and E1 is distinct. The distinction between Units E and D is a little unclear, as a clay interval is present between two beds of sand that could be assigned to Dc3, or retained as part of E1. The pyrite in both sand layers in question indicates that it may be one unit with a minor clay interbed. However, assigning both sand beds to E1 means that Dc3 is missing in CD-1-779. Most of the remainder of the cored interval is assigned to Dc2, with 20 cm of Dw4 intersected to the base.

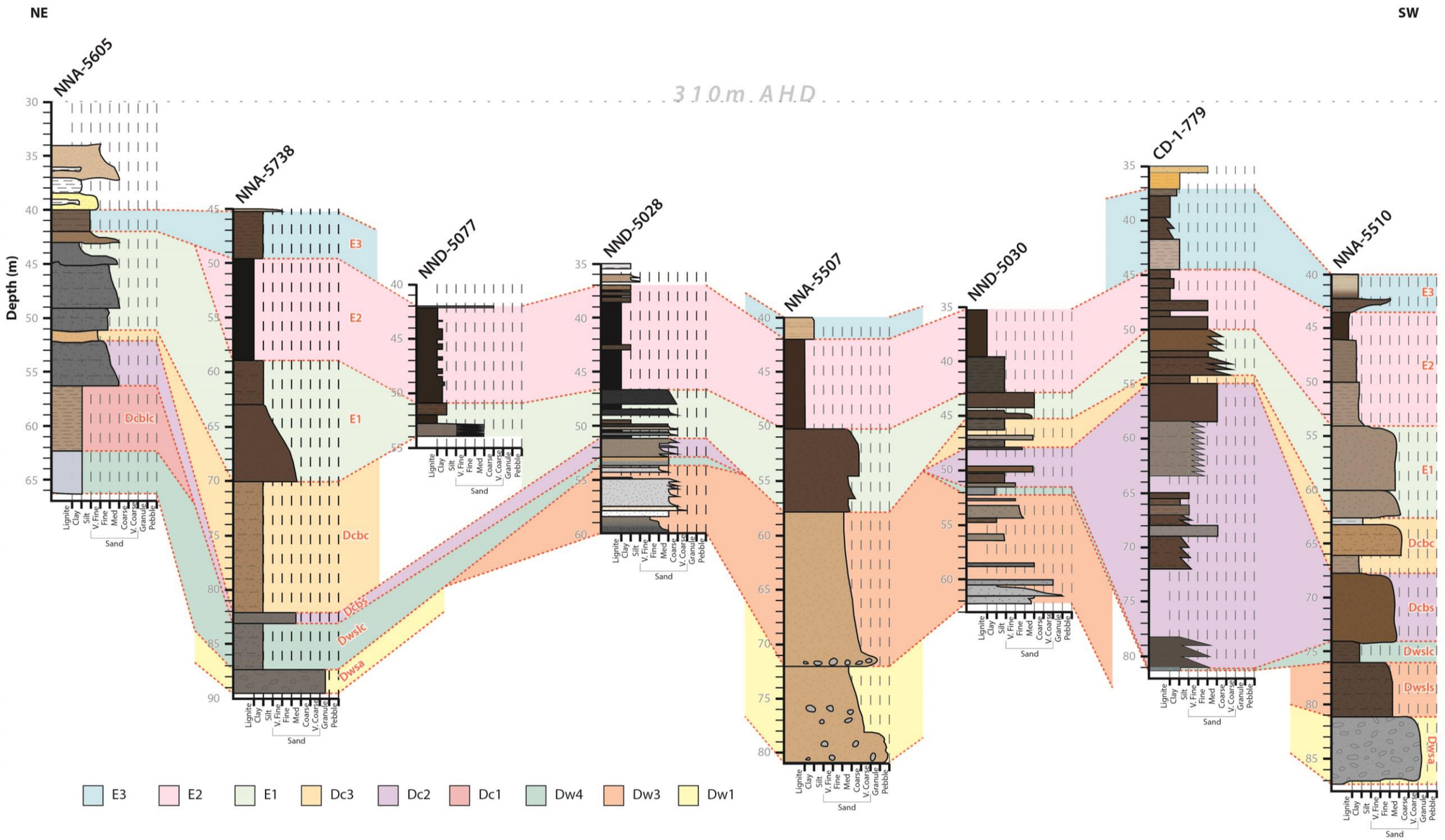


Fig. 7.2 Correlation of Vimy Resources' stratigraphic units across study cross section. Compiled from raw logging data provided by Vimy Resources. Tops of drill logs are correlated to a 310 relative sea level datum but the depth scales for individual logs remain as drilled from surface.

7.1.2 Air core holes (NNA-5605, NNA-5738, NNA-5507, NNA-5510)

Most of the air core material was logged on a much coarser scale than the diamond core holes. Some of the interbeds that were described for the diamond cores therefore appear absent in the air core logs.

NNA-5605: The carbonaceous E3 interval started at 40 m depth, with a black to brown siltstone. However, this unit directly overlies sandstones of the E1 interval. The characteristic lignite of the E2 interval is absent at this location in the basin. All D interval subunits, except for the Dc3 claystone unit, are present with coring ending within Dw4.

NNA-5738: All three subdivisions of Unit E are present and easily distinguishable. Unit E2 comprises 9.5 m of black lignite and a clear boundary with the sands assigned to the E1 interval. Unit D can also be subdivided; with the subunits Dc3, Dc2, Dw4 and Dw1 present. Dc3 is unusually thick in this core, with the interval being 12 m thick. Dc2 is comparatively thin (1 m), but reaches up to 30 m elsewhere at Mulga Rock. The carbonaceous clay (Dc1) underlying Dc2 is absent. Dw3 is also absent, with Dw4 directly overlying Dw1. Only the one conglomeratic layer is present, with Dw2 not recorded.

NNA-5507: All three subunits of E, as defined in Vimy's stratigraphic scheme, are present in NNA-5507. Several of the subunits of the D interval are absent however, with E1 directly overlying sands that can be assigned to Dw3. A conglomerate was logged within the sands assigned to Dw3 that may represent Dw2, overlying a second conglomerate that has been assigned to Dw1.

NNA-5510: All subunits of Unit E are present; however, E2 and E1 are markedly less carbonaceous than in other drill holes. The fining up of the E1 interval is also not as clear in NNA-5510. Dc3 underlies Unit E, but includes 3 m of fine to medium goethitic sand. The division of the unit after this point is unclear, as the standard stratigraphy describes a distinct colour change at Dw4. In NNA-5510 the sedimentary packages are distinctly carbonaceous and brown, extending to the

ravinement layer represented by Dw1. The interval between the base of Dc3 and the start of Dw1 may be interpreted to be entirely Dc2 (with a 2 m clay layer in the middle of the unit), or to be subdivided into Dc2, Dc1 and Dw3. The latter option means that Dw3 is unusually carbonaceous at this interval. In all cases Dw4 is absent.

7.2 Distribution of major spore and pollen groups and individual species

Authors for all species noted in this section are listed in Chapters 5 and 6 (Systematics) and Appendix 9. The diamond core drill hole and the air core drill holes are discussed separately.

7.2.1 Diamond core (NND-5077, NND-5028, NND-5030, CD-1-779)

The diamond core sampled for this study was preserved as it was cored at the Mulga Rock Project site. This allowed for significantly finer sampling and a better determination of the distribution of major spore and pollen groups over contacts in the lithostratigraphy. For example, the boundary between E1 and E2 in NND-5077 was determined to be somewhere between samples collected within 20 cm of each other. Changes in pollen distribution within individual cores are outlined below and in Appendix 3.

NND-5077: (Fig.7.3 and Table 7.1) Fine sampling through NND-5077 allows for the E1/E2 boundary to be placed between 52.5 m and 52.7 m. Percentages of *Haloragacidites harrisii* are significantly lower through E1 (6-12%). These increase into the lignitic E2 (10.5-28.5%), with the species significantly concentrated at the base of the unit (28.5%). The amount of *Tricolporites* spp. present in the count decreases from 16.5% to 9.5% over the boundary between E1 and E2. The percentage occurrence of gymnosperm species increases from 1% to 9.5% over the same boundary. The top of E1 in this location has a significantly high percentage of proteaceous pollen (17%), in comparison to other samples in this study. There is no marked change in the presence of *Nothofagidites* spp. between E1 and E2, but the

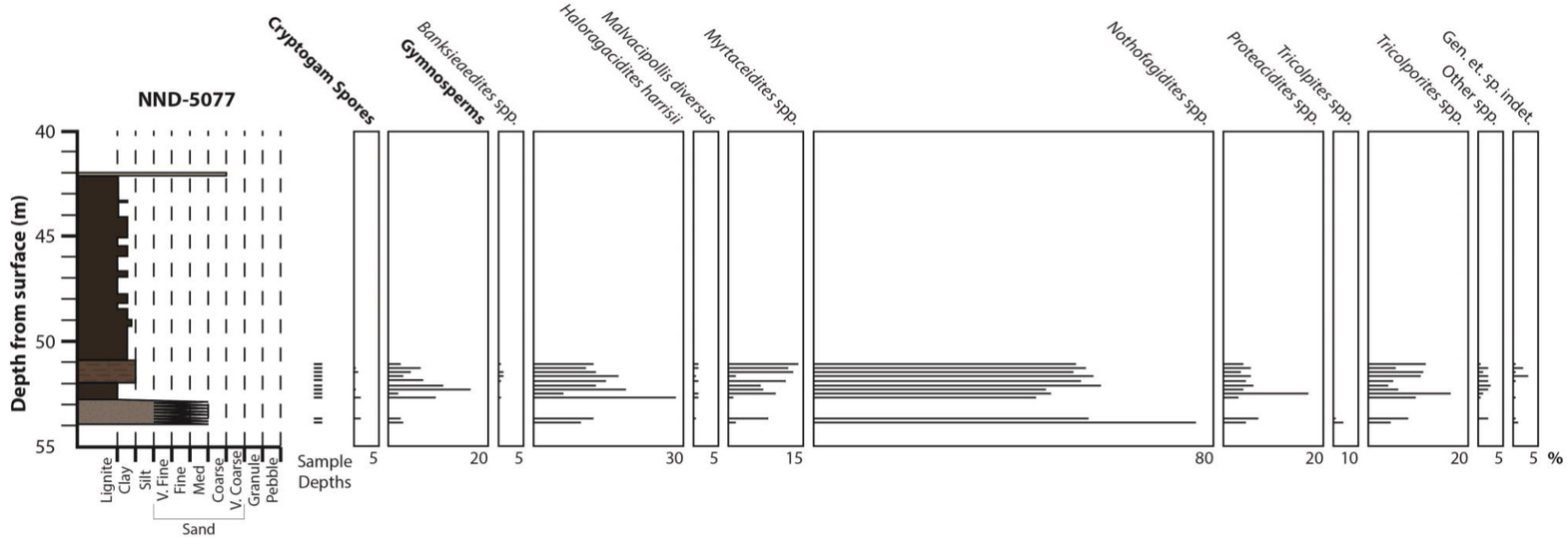


Fig. 7.3 Distribution of major pollen groups in samples studied from drill hole NND-5077

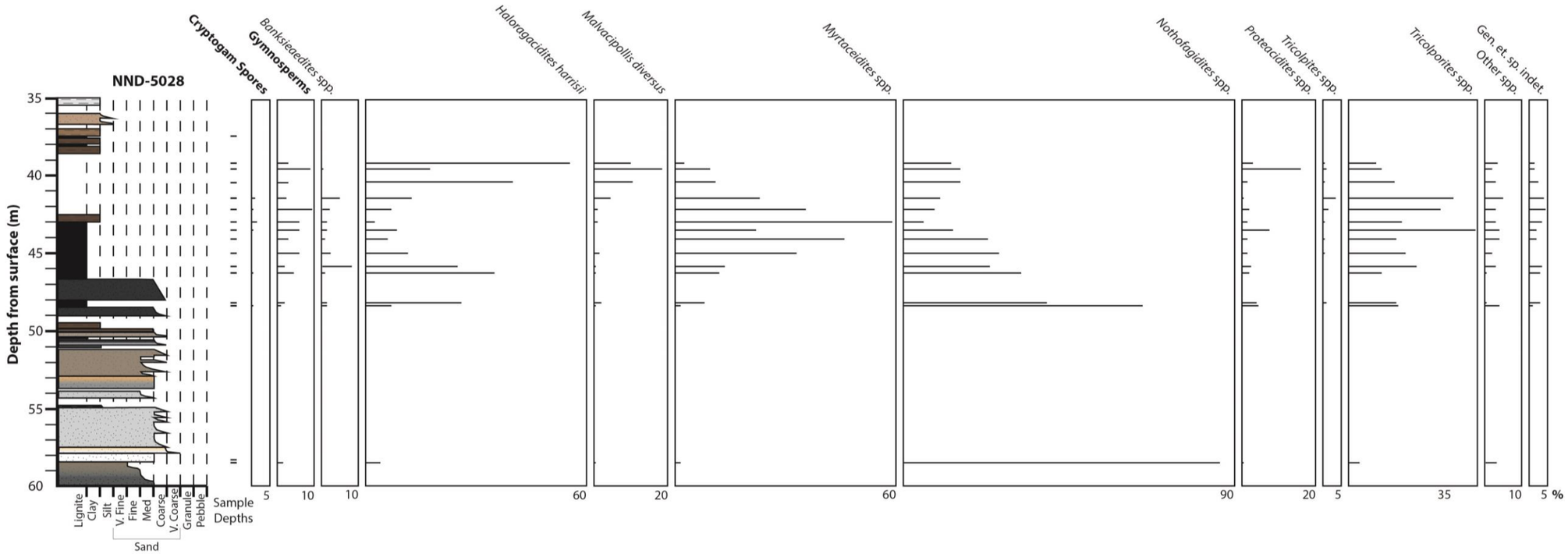


Fig. 7.4 Distribution of major pollen groups in samples studied from drill hole NND-5028

Table 7.1 Percent occurrence of major pollen groups in NND-5077. Compiled from 200-grain counts. The raw data are listed in Appendix 3.

Drill Program	**NND**										
Drill Hole	**5077**										
Depth (m)	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1	E1
Cryptogam Spores	0	0.5	1	0	0	0	0.5	1.5	0	1.5	0
Gymnosperms											
Podocarpidites spp.	1	3	0.5	0.5	2	4	4.5	2	0	1	0.5
Lygistepollenites florinii	1	2	3	1.5	2	5.5	7.5	6.5	0.5	1.5	2.5
Other Gymnosperm spp.	0.5	1.5	1	1	3	1.5	3.5	1	0.5	0	0
Total gymnosperms	2.5	6.5	4.5	3	7	11	15.5	9.5	1	2.5	3
Angiosperms											
Banksieaeidites spp.	0.5	0	1	1	0.5	0	0	0.5	0	0	0
Haloragacidites harrisii	12	10.5	12.5	17	14.5	12.5	18.5	28.5	6	12	9.5
Nothofagidites spp.	52.5	54.5	52	56	53.5	57.5	46.5	44.5	47.5	55	76.5
Myrtaceidites spp.	14	12	13	1.5	11.5	6.5	7	1	9.5	8	1.5
Proteacidites spp.	4	5.5	3.5	5.5	4.5	6	4	3	17	9.5	2
Tricolporites spp.	11.5	6	11	10.5	5	4	7.5	9.5	16.5	8	4.5
Tricolpites spp.	0	0	0.5	0.5	0	0.5	0	0	0.5	0.5	2
Malvacipollis diversus	1	1	0	0.5	1	0	0	1	1	0.5	0
Other spp.	0.5	1.5	0.5	1.5	2	2	0.5	0.5	1	2	0
Gen. *et*. sp. indet.	1.5	2	0.5	3	0.5	0	0	0.5	0	0.5	1
	100	100	100	100	100	100	100	100	100	100	100

Table 7.2 Percent occurrence of major pollen groups in NND-5028. Compiled from 200-grain counts. The raw data are listed in Appendix 3.

Drill Program								**NND**							
Drill Hole								**5028**							
Depth (m)	37.5	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3	58.5
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1	Dw4	Dw4
Cryptogam Spores	0	0	0	0	1	0.5	1.5	0.5	0	0	0	0.5	0	0.5	0	0
Gymnosperms																
Podocarpidites spp.	0	2	3	2.5	1	7.5	5	4	2.5	5	1.5	2	0	0	0	1.5
Lygistepollenites florinii	0	1	6	0	1	1.5	1	2	0.5	0	0.5	2	2	0.5	0	2
Other spp.	0	0	0	0.5	0.5	0.5	0	0	0	1	0	0.5	0	0.5	0	0.5
Total gymnosperms		3	9	3	2.5	9.5	6	6	3	6	2	4.5	2	1	0	4
Angiosperms																
Banksieaeidites spp.	0	0	0.5	0	5	2	1.5	1.5	1	2.5	8	1	1.5	1.5	0	1.5
Haloragacidites harrisii	0	55.5	17.5	40	12.5	7	2.5	8.5	6	11.5	25	35	26	7	0	29.5
Nothofagidites spp.	0	13	15.5	15.5	10	8.5	5.5	13.5	23	26	23.5	32	39	65	0	20.5
Myrtaceidites spp.	0	2.5	9.5	11	23	35.5	59	22	46	33	13.5	12	8	1.5	0	16
Proteacidites spp.	0	3	16	1.5	0.5	2	1.5	7.5	1.5	1.5	2.5	2	4	4.5	0	5
Tricolporites spp.	0	7.5	9	12.5	28.5	25	14.5	34.5	13	15.5	18.5	9	13	13.5	0	14
Tricolpites spp.	0	2.5	1	0.5	4.5	1.5	0.5	0.5	0.5	1.5	2.5	0	1.5	2	0	3.5
Malvacipollis diversus	0	10	18.5	10.5	4.5	1	1	0	0	1.5	0.5	0.5	2	0.5	0	4.5
Other spp.	0	1.5	2	3	4	3	3	3.5	4	1	0.5	0.5	0	2	0	1
Gen. et. sp. indet.	0	1.5	1.5	2.5	4	4.5	3.5	2	2	0	3.5	3	3	1	0	0.5
	0	100	100	100	100	100	100	100	100	100	100	100	100	100	0	100

percentages present decreases from 76.5% to 47.5% through the E1 interval, and remains relatively consistent through E2, ranging from 44.5% to 57.5 %.

NND-5028: (Fig 7.4 and Table 7.2) Sampling from NND-5028 includes a boundary between E1 and E2 between 46.3 m and 48.2 m, and a contact between Dw4 and E1 between 48.4 m and 58.3 m. A similar increase in *Haloragacidites harrisii* that was observed in NND-5077 was apparent in NND-5028, with concentrations of 26% at the top of E1 and 35% at the base of E2. The percentage occurrence of *H. harrisii* is higher at the base of E2 (but the increase is spread across 3.2 m), decreases in the middle of E2 to as low as 2.5% and again increases to 55.5 % at the top of E2. Also of note are the high concentration (10-18.5%) of *Malvacipollis diversus* in the upper few metres of E2, and the high concentration of *Myrtaceidites* spp in E2 as compared to that in NND-5077. Where *Myrtaceidite*s spp. are high, the percentages of *H. harrisii* and *Nothofagidites* spp are comparatively low. The percentage of *Nothofagidites* spp. also decreases across the E1 and E2 boundary in NND-5028. Dw4 is distinguished from E1 by a higher percentage of gymnosperm species and *Tricolpites* spp.

NND-5030: (Fig. 7.5 and Table 7.3) Several general trends are apparent in the percentage presence of major spore and pollen groups in NND-5030. An increase in the total percentage of gymnosperms makes a distinction between the units Dw3 and Dc2. *Haloragacidites harrisii* is present at lower amounts in Dc2 than in Dc3. *Myrtaceidites* spp. decrease through the subunits of D, from up to 32.5% in Dw3 at the base of the D unit to 11.5% in Dc2 and 3%
in Dc3. Samples from interval E1 processed from NND-5030 were barren. A high percentage of *H. harrisii* (29.5%) appears to be associated with the base of subunit E2. *Myrtaceidites* spp. increases into the upper half of E2 from 16% to 44.5%. This is associated with a decrease in *Nothofagidites* spp. through E2, being as low as 4.5% at 37.2 m.

CD-1-779: (Fig. 7.6 and Table 7.4) Comparisons between Dc2 and E1 are not possible as E1 was not sampled from CD-1-779. The percent occurrence of proteaceous pollen decreases between Dc2 and E2 (6.5-7% to 2% in E2) and *H.*

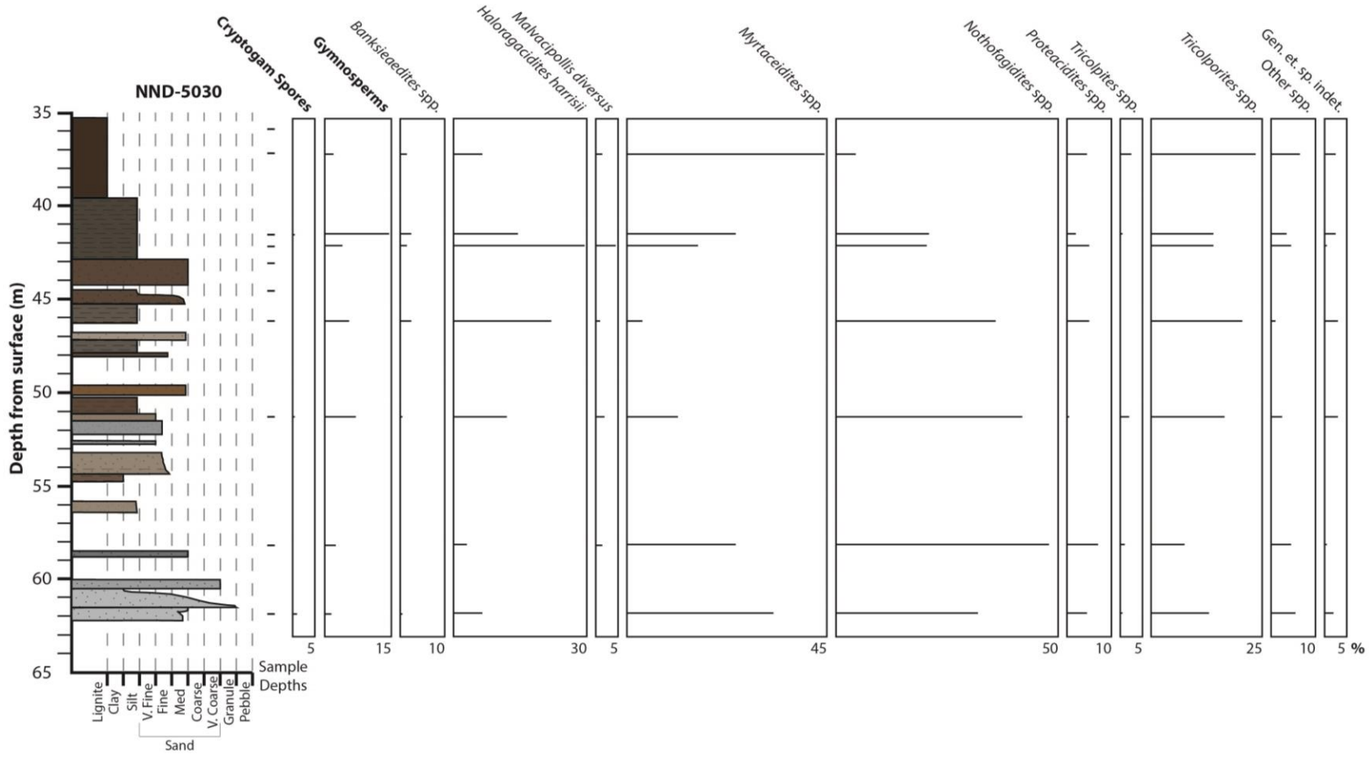


Fig. 7.5 Distribution of major pollen groups in drill hole NND-5030

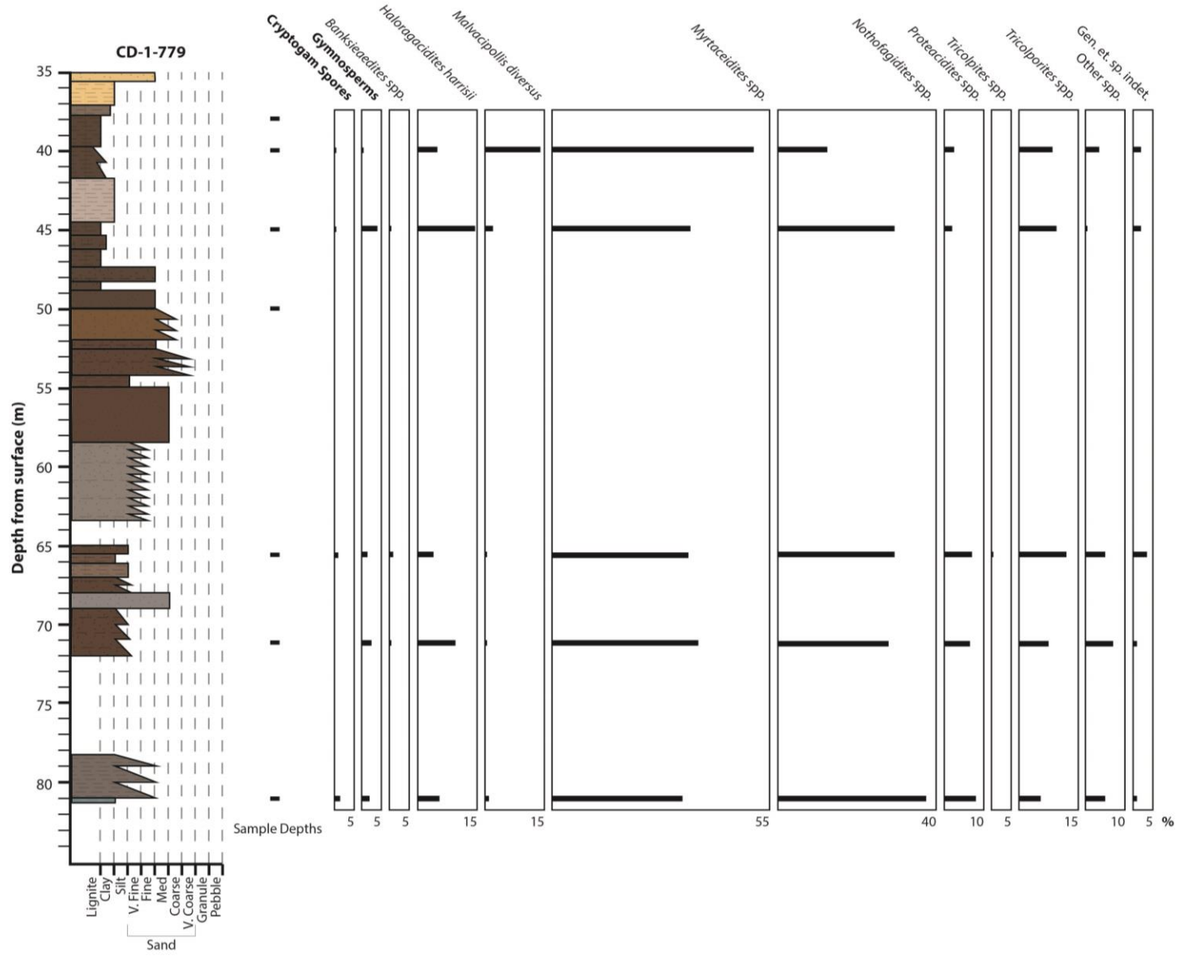


Fig. 7.6 Distribution of major pollen groups in drill hole CD-1-779

Table 7.3 Percent occurrence of major pollen groups in NND-5030. Compiled from 200-grain counts. The raw data are listed in Appendix 3.

Drill Program					**NND**					
Drill Hole					**5030**					
Depth (m)	35.9	37.2	41.6	42.2	43	44.6	46.2	51.3	58.2	61.8
Lithological Interval	E2	E2	E2	E2	E1	E1	Dc3	Dc2	Dw3	Dw3
Cryptogam Spores	0	0	0.5	0	0	0	0	0.5	0	1
Gymnosperms										
Podocarpidites spp.	0	0	11.5	1.5	0	0	2	3.5	2	1
Lygistepollenites florinii	0	0.5	2.5	2	0	0	3.5	2	0.5	0.5
Other Gymnosperm spp.	0	1.5	0.5	0.5	0	0	0	1.5	0	0
Total gymnosperms	0	2	14.5	4	0	0	0	7	2.5	1.5
Angiosperms										
Banksieaeidites spp.	0	1.5	2.5	1.5	0	0	2.5	0.5	0	0.5
Haloragacidites harrisii	0	6.5	14.5	29.5	0	0	22	12	3	6.5
Nothofagidites spp.	0	4.5	21	20.5	0	0	36	42	48	32
Myrtaceidites spp.	0	44.5	24.5	16	0	0	3	11.5	24.5	32.5
Proteacidites spp.	0	4.5	2	5	0	0	5	0.5	7	4.5
Tricolporites spp.	0	23.5	14	14	0	0	20.5	16.5	7.5	13
Tricolpites spp.	0	3.5	1	3.5	0	0	0	2	1	0.5
Malvacipollis diversus	0	1.5	0	4.5	0	0	1	2	1.5	0
Other spp.	0	5.5	3	1	0	0	1	2.5	4.5	5.5
Gen. et. sp. indet.	0	2.5	2.5	0.5	0	0	3	3	0.5	2
	0	100	100	100	0	0	100	100	100	100

Table 7.4 Percent occurrence of major pollen groups in CD-1-779. Compiled from 200-grain counts. The raw data are listed in Appendix 3.

Drill Program					**CD-1**		
Drill Hole					**779**		
Depth (m)	38	40	45	50	65.6	71.3	81
Lithological Interval	E3	E3	E2	E2	Dc2	Dc2	Dw4
Cryptogam Spores	0	0.5	0.5	0	1	0	1.5
Gymnosperms							
Podocarpidites spp.	0	0.5	3	0	0	2	1
Lygistepollenites florinii	0	0	0.5	0	1	0	1
Other Gymnosperm spp.	0	0	0.5	0	0.5	0.5	0
Total gymnosperms	0	0.5	4.0	0	1.5	2.5	2
Angiosperms							
Banksieaeidites spp.	0	0	0.5	0	1	0.5	0
Haloragacidites harrisii	0	5	14.5	0	4	9.5	5.5
Nothofagidites spp.	0	12.5	29.5	0	29.5	28	37.5
Myrtaceidites spp.	0	51	35	0	34.5	37	33
Proteacidites spp.	0	2.5	2	0	7	6.5	8
Tricolporites spp.	0	8.5	9.5	0	12	7	5.5
Tricolpites spp.	0	0	0	0	3	0	0
Malvacipollis diversus	0	14	2	0	0.5	0.5	1
Other spp.	0	3.5	0.5	0	2.5	7.5	5
Gen. et. sp. indet.	0	2	2	0	3.5	1	1
	0	100	100	0	100	100	100

harrisii increases from 4% to 14.5%. Unit E2 can be distinguished from E3 by a slight decrease in the gymnosperm percentage from 4% to 0.5%, The E3 interval in this drill hole can also be distinguished by a high percentage (14%) of *Malvacipollis diversus*, whereas the high concentration of *M. diversus* has been recorded from the upper portion of E2 in drill hole NNA-5738.

7.2.2 Air core drill holes (NNA-5605, NNA-5738, NNA-5507, NNA-5510)

Most of the air core in this study was stored in bags that contained combined samples from 0.5 m to 2 m of the sedimentary succession. This made the fine distinction of boundaries within the section difficult, but it was still possible to determine general trends in the percentage distribution of major palynomorph groups.

NNA-5605: (Fig. 7.7 and Table 7.5) Samples of Dw4 were barren in this drill hole, and E2 was absent. *Proteacidites* spp. decreases from 7.5% to 5% between Dc2 and E1. A higher percentage of *Nothofagidites* spp. in E1 (60.5-57.5%) distinguishes it from E3 (37%) in NNA-5605.

NNA-5738: (Fig. 7.8 and Table 7.6) Only those samples from Unit E in NNA-5738 were productive. The uppermost sample in E1 and the lowermost from E2 are six metres apart, but a distinct difference between the two intervals is apparent. The percentage of *Haloragacidites harrisii* increases from 11% to 29.5% between E1 and E2. The percentage of *Malvacipollis diversus* was also higher in E2 (4.5–7% from 49–53 m). *Tricolporites* spp. decreases into E2 (18.5% in E1 to 4.5% in E2). The percent occurrence of *Tricolporites* spp. is higher for all samples of E1 than those of E2. The concentration of *Proteacidites* spp. is unusually high (13.5%) in the lowermost E2 sample (52-53 m) but this is mostly due to a relatively large percentage of *P. cirritulus* (4%). The percentage of *Myrtaceidites* spp. increases through E1 from 16.5% in the lowermost sample (64-65 m) to 35% in the uppermost sample (59-60 m). The percentage occurrence then decreases into E2 (16.5-22%). It is possible that further sampling of NNA-5738 will better constrain the boundary in this drill hole.

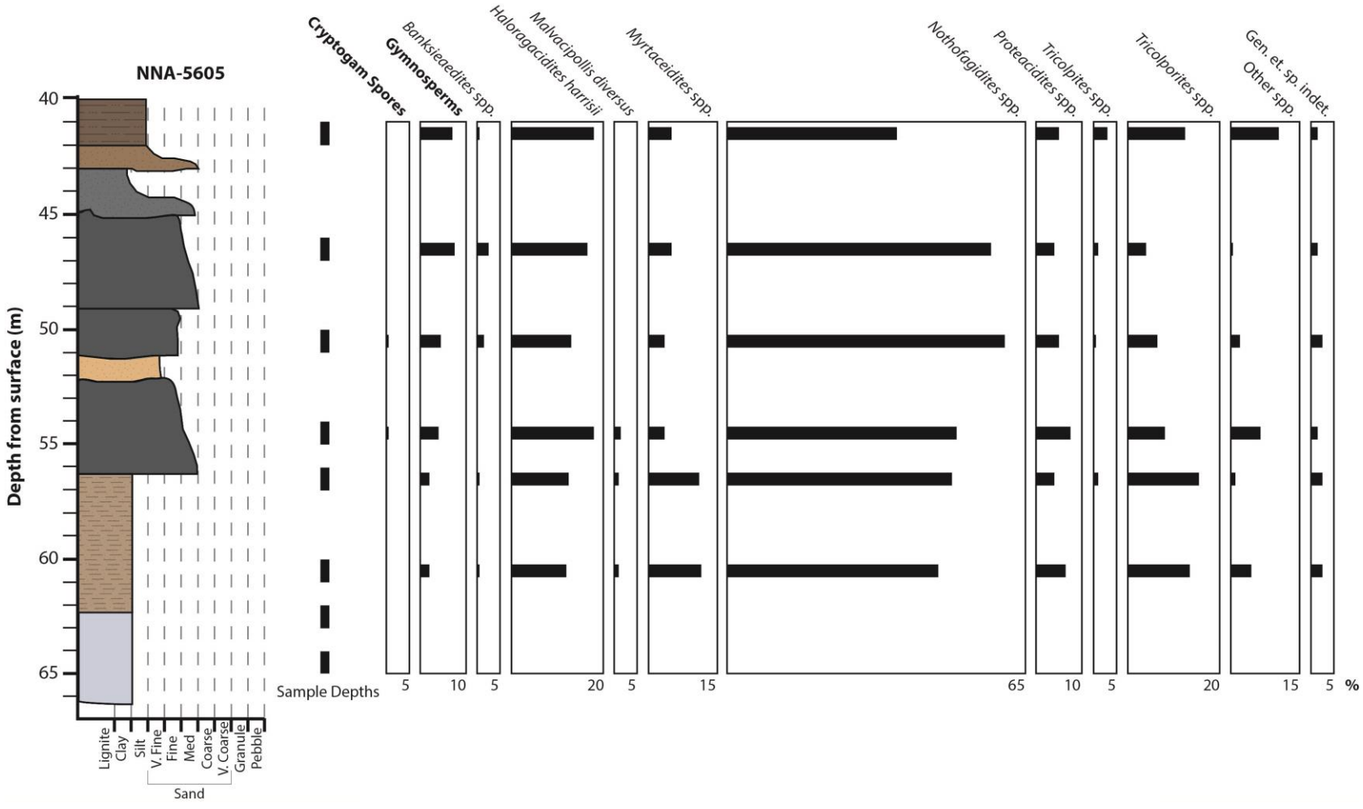


Fig. 7.7 Distribution of major pollen groups in drill hole NNA-5605

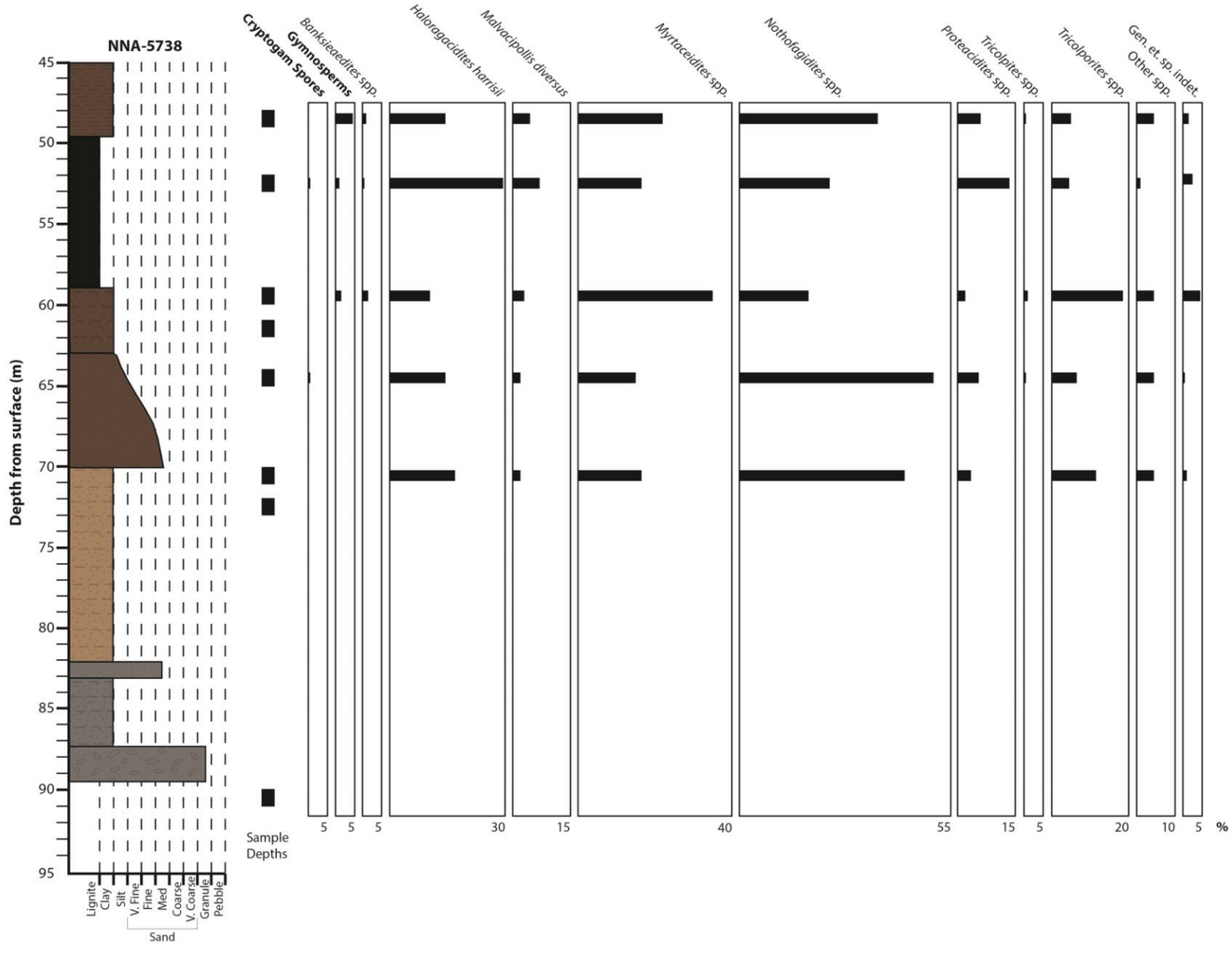


Fig. 7.8 Distribution of major pollen groups in drill hole NNA-5738

Table 7.5 Percent occurrence of major pollen groups in NNA-5605. Compiled from 200-grain counts. The raw data are listed in Appendix 3.

Drill Program				**NNA**			
Drill Hole				**5605**			
Depth (m)	41-42	46-47	50-51	54-55	56-57	60-61	62-63	64-65
Lithological Interval	E3	E1	E1	Dc2	Dc1	Dc1	Dw4	Dw4
Cryptogam Spores	0	0	0.5	0.5	0	0	0	0
Gymnosperms								
Podocarpidites spp.	6	4	1	1.5	0.5	0	0	0
Lygistepollenites florinii	1	3	3	2.5	1.5	1.5	0	0
Other Gymnosperm spp.	0	0.5	0.5	0	0	0.5	0	0
Total gymnosperms	7	7.5	4.5	4	2	1.5	0	0
Angiosperms								
Banksieaeidites spp.	0.5	2.5	1.5	0	0.5	0.5	0	0
Haloragacidites harrisii	18	16.5	13	18	12.5	12	0	0
Nothofagidites spp.	37	57.5	60.5	50	49	46	0	0
Myrtaceidites spp.	5	5	3.5	3	11	11.5	0	0
Proteacidites spp.	5	4	5	7.5	4	6.5	0	0
Tricolporites spp.	12.5	4	6.5	7.5	15.5	14	0	0
Tricolpites spp.	6	1.5	0.5	0	1	1	0	0
Malvacipollis diversus	0	0	0	1.5	1	1	0	0
Other spp.	7.5	0	2	6.5	1	3	0	0
Gen. *et.* sp. indet.	1.5	1.5	2.5	1.5	2.5	2.5	0	0
	100	100	100	100	100	100	0	0

Table 7.6 Percent occurrence of major pollen groups in NNA-5738. Compiled from 200-grain counts. The raw data are listed in Appendix 3.

Drill Program			**NNA**				
Drill Hole			**5738**				
Depth (m)	49-50	52-53	59-60	61-62	64-65	70-71	72-73
Lithological Interval	E2	E2	E1	E1	E1	Dc3	Dc3
Cryptogam Spores	0	0.5	0	0	0.5	0	0
Gymnosperms							
Podocarpidites spp.	3.5	0	0	0	0.5	0	0
Lygistepollenites florinii	1	0.5	0.5	0.5	0	0	0
Other Gymnosperm spp.	0	0.5	0.5	0	0	0	0
Angiosperms							
Banksieaeidites spp.	1	0.5	1.5	0	0	0	0
Haloragacidites harrisii	14.5	29.5	11	14.5	17	0	0
Nothofagidites spp.	36	23.5	18	50.5	43	0	0
Myrtaceidites spp.	22	16.5	35	15	16.5	0	0
Proteacidites spp.	6	13.5	2	5.5	3.5	0	0
Tricolporites spp.	5	4.5	18.5	6.5	11.5	0	0
Tricolpites spp.	0.5	0	1	1	1	0	0
Malvacipollis diversus	4.5	7	3	2	2	0	0
Other spp.	4.5	1	4.5	4	3.5	0	0
Gen. *et.* sp. indet.	1.5	2.5	4.5	0.5	1	0	0
	100	100	100	100	100	0	0

NNA-5507: (Fig. 7.9 and Table 7.7) The most significant changes between Dw3 and E1 are a decrease in *Proteacidites* spp., from 13 % in Dw3 to 6.5% in E1and an increase in *H. harrisii* from 1.5% in Dw3 to 14.5% in E1. The percent occurrence of *Nothofagidites* spp. decreases through the E1 interval from 56.5% to 40%. A slight decrease also occurs over the boundary between E1 and E2 (from 40% to 33%). The boundary between E1 and E2 can also be distinguished by a slight increase in *Tricolporites* spp. and a significant increase in *Myrtaceidites* spp. from 12.5% in E1 to 26.5% in E2.

NNA-5510: (Fig. 7.10 and Table 7.8) In NNA-5510, Dc2 can be distinguished from the E2 samples by a higher percent occurrence of *Nothofagidites* spp. and lower percentages of *Myrtaceidites* spp., in the top two samples in particular. Percentages of *H. harrisii* in E2 are unusually low (9-14.5%) for this interval. This could be due to the sampling gap over the Dc2/E2 boundary, with the higher concentrations associated with the base of E2. Concentrations of *Tricolporites* spp. are also

Table 7.7 Percent occurrence of major pollen groups in NNA-5507. Compiled from 200-grain counts. The raw data are listed in Appendix 3.

Drill Program			**NNA**			
Drill Hole			**5507**			
Depth (m)	47-48	52-53	54-55	59-60	71-72	73-74
Lithological Interval	E2	E1	E1	Dw3	Dw1	Dw1
Cryptogam Spores	0	0	0	0	0	0
Gymnosperms						
Podocarpidites spp.	4.5	6	3	1.5	0	0
Lygistepollenites florinii	2	2	4	0	0	0
Other Gymnosperm spp.	0	1	0.5	0	0	0
Total gymnosperms	6.5	9	7.5	1.5	0	0
Angiosperms						
Banksieaeidites spp.	0	2	1	3	0	0
Haloragacidites harrisii	10	6.5	11	1.5	0	0
Nothofagidites spp.	33	40	56.5	46.5	0	0
Myrtaceidites spp.	26.5	12.5	6.5	15.5	0	0
Proteacidites spp.	5.5	4.5	6.5	13	0	0
Tricolporites spp.	11	19	6	8.5	0	0
Tricolpites spp.	2	2.5	0.5	3	0	0
Malvacipollis diversus	2.5	1	0.5	0.5	0	0
Other spp.	2	1	1.5	4.5	0	0
Gen. *et*. sp. indet.	1	2	2.5	2.5	0	0
	100	100	100	100	0	0

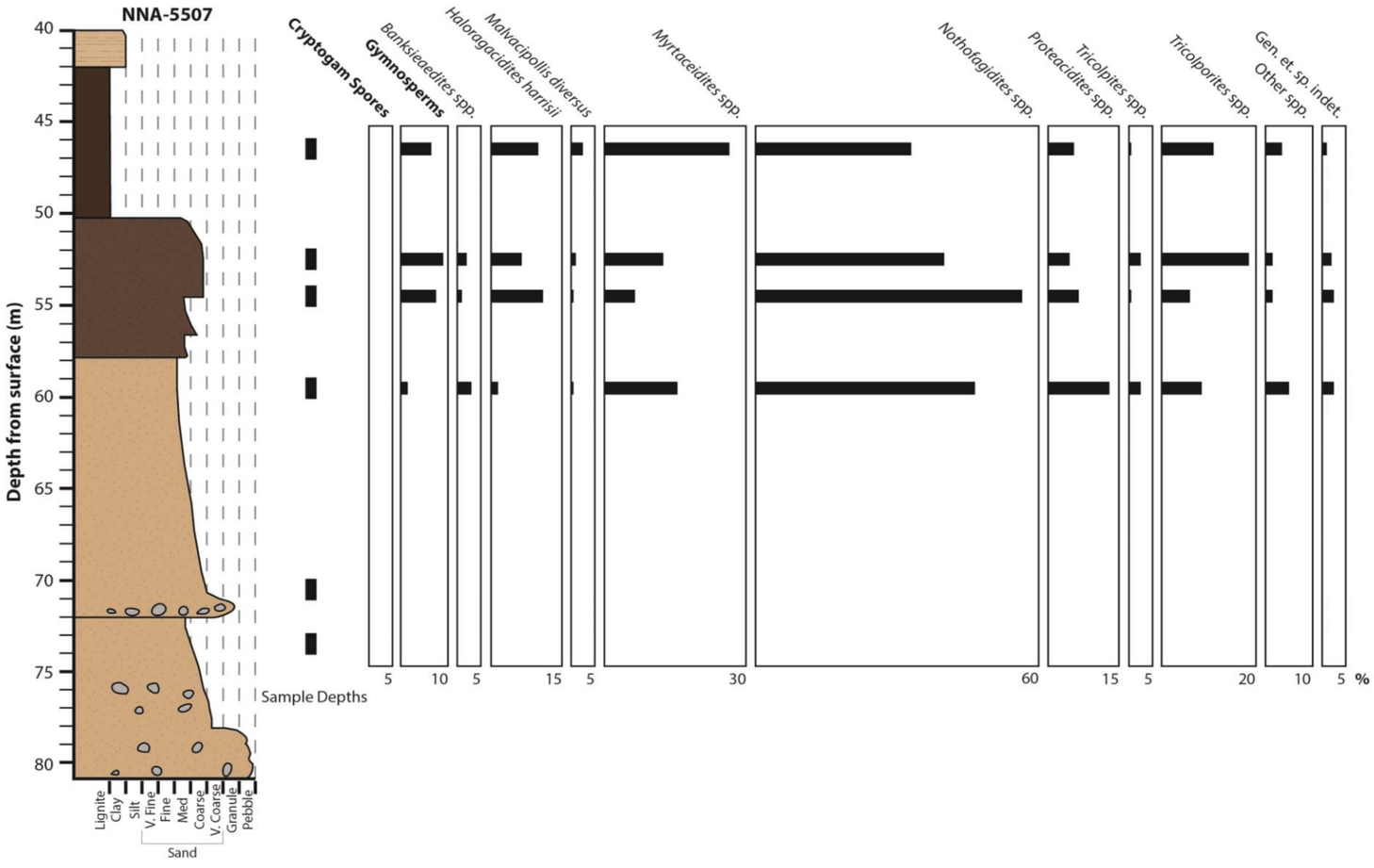


Fig. 7.9 Distribution of major pollen groups in drill hole NNA-5507

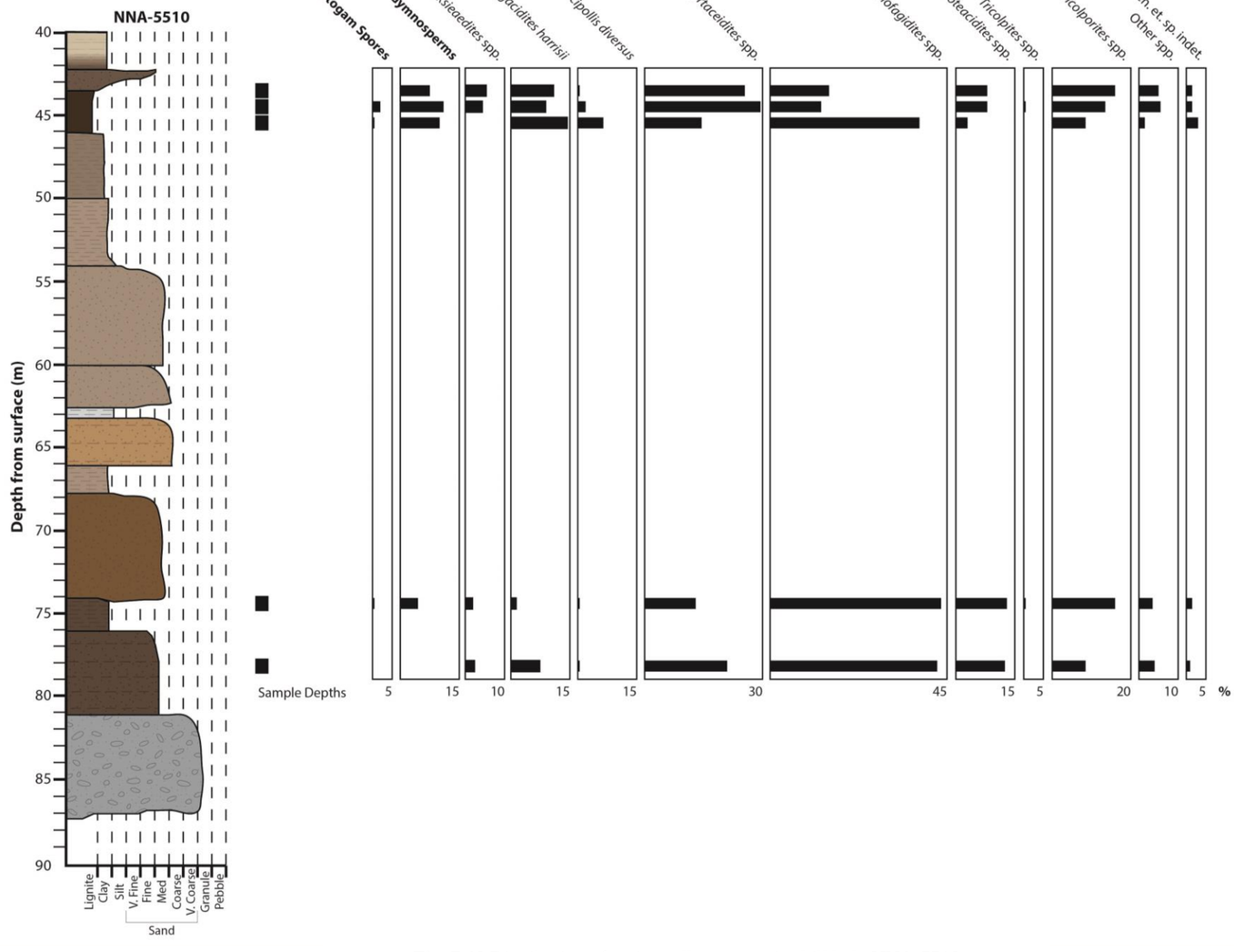


Fig. 7.10 Distribution of major pollen groups in drill hole NNA-5510

unusually high (8.5-16%) for the E2 interval. The 43 to 44 m sample likely includes sediments from E2 and E3, which may explain the 16%, but the remainder of the E2 samples also include a relatively high concentration of *Tricolporites* spp. *Malvacipollis* is high (6.5%) in the lowest sample from E2. The distance of 2 km between NNA-5510 and CD-1-779 may explain the unusual distributions of major groups in this drill hole.

Table 7.8 Percent occurrence of major pollen groups in NNA-5510. Compiled from 200-grain counts. The raw data are listed in Appendix 3.

Drill Program			**NNA**			
Drill Hole			**5510**			
Depth (m)	43-44	44-45	45-46	74-75	78-79	103-104
Lithological Interval	E2	E2	E2	Dc2	Dc2	Dw1
Cryptogam Spores	0	2	0.5	0.5	0	0
Gymnosperms						
Podocarpidites spp.	6.5	7	5	0.5	0	0
Lygistepollenites florinii	5	2.5	4	0.5	0	0
Other gymnosperm spp.	0.5	1.5	1	3.5	0	0
Total gymnosperms	7.5	11	10	4.5	0	
Angiosperms						
Banksieaeidites spp.	5.5	4.5	0	2	2.5	0
Haloragacidites harrisii	11	9	14.5	1.5	7.5	0
Nothofagidites spp.	15	13	38	43.5	42.5	0
Myrtaceidites spp.	25.5	29.5	14.5	13	21	0
Proteacidites spp.	8	8	3	13	12.5	0
Tricolporites spp.	16	13.5	8.5	16	8.5	0
Tricolpites spp.	2	1.5	1	0.5	0	0
Malvacipollis diversus	0.5	2	6.5	0.5	0.5	0
Other spp.	3	4.5	0.5	3.5	4	0
Gen. *et*. sp. indet.	1.5	1.5	3	1.5	1	0
	100	100	100	100	100	0

7.2.3 Stratigraphic palynomorph trends

The most significant stratigraphic trends observed in the distribution of major pollen and spore groups are for the boundary between E2 and E1 (Table 7.9). These trends occur in several of the drill holes studied. The percentage of *Haloragacidites harrisii* in counts increases from E1 into E2, before decreasing through the E2 interval; occurring in NND-5030 (14.5–29.5% in E2), NND-5077 (6% in E1 to 28.5% in E2 then decreasing to 18.5%), NNA-5738 (11% in E1 increasing to 14.5% in E2, then

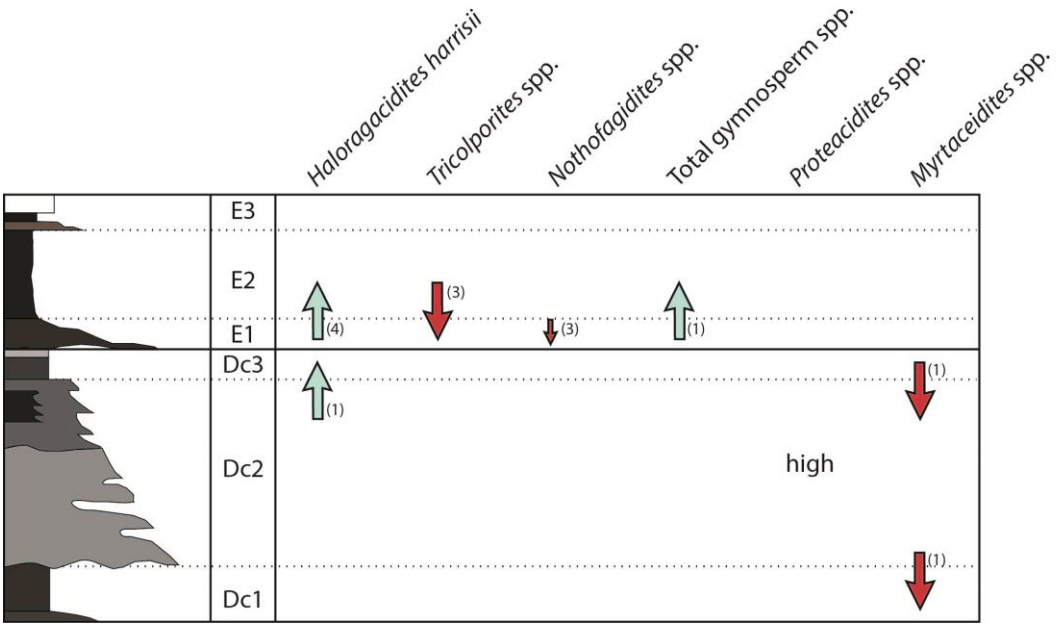


Fig. 7.11 Changes in percent occurrence of major pollen groups in drill holes studied. Bracketed numbers represent the number of drill holes the trend occurred in.

occurring in NND-5030 (14.5–29.5% in E2), NND-5077 (6% in E1 to 28.5% in E2 then decreasing to 18.5%), NNA-5738 (11% in E1 increasing to 14.5% in E2, then decreasing to 11%) and NND-5028 (7% in E1 to 26% in E2). The percent occurrence of *Tricolporites* spp. also shows a decrease from the top of E1 into E2; in NND-5077 (16.5% in E1 to 9.5% in E2), NNA-5507 (19% in E1 to 11% in E2) and NNA-5738 (18.5% in E1 to 4.5% in E2). A consistent change in *Nothofagidites* spp. across the E1/E2 boundary is not apparent, but a steady decrease in their presence throughout E1 is of note in NNA-5738 (50.5% to 18%), NND-5077 (76.5% to 47.5%), and NNA-5507 (56.5% to 40%).

Table 7.9 Trends in percent occurrence of three major pollen groups in Unit E in five drill holes.

Strat. Unit	NND-5030	NND-5077	NNA-5738	NND-5028	NNA-5507
			Haloragacidites harrisii		
E2	14.5	18.5	11		
Base E2	29.5	28.5	14.5	26	
E1	barren	6	11	7	
			Tricolporites spp.		
E2		9.5	4.5		11
E1		16.5	18.5		19
			Nothofagidites spp.		
Top E1		47.5	18		40
Base E1		76.5	50.5		56.5

Some percentage changes occur at the E1/E2 boundary only within one drill hole (Table 7.10). An increase in gymnosperms between E1 and E2 occurs in NND-5077 (from 1% in E1 to 9.5% in E2). A distinct decrease in *Nothofagidites* spp. occurs between the two subunits in NND-5028 (from 65% in E1 to 39% in E2). A decrease in proteaceous pollen at the E1/E2 boundary in NND-5077 also occurs (17% in E1 to 3% in E2). However, an increase occurs into E2 in NNA-5738, with *Proteacidites* spp. recorded at 2% in E1 and 13.5% in E2. Study of assemblages from further drill holes along the cross section may determine if any of these trends can assist in defining the boundary between E1 and E2.

Table 7.10 Trends in the percent occurrence of three major pollen groups occurring across the E1/E2 boundary in three drill holes.

Strat. Unit	NND-5077	NNA-5738	NND-5028
Total gymnosperm spp.			
E2	9.5		
E1	1		
Nothofagidites spp.			
E2			39
E1			65
Proteacidites spp.			
E2	3	13.5	
E1	17	2	

No consistent trends in the distribution of groups between the E and D intervals were recognised, though several changes between D subunits are of note (Table 7.11). A higher percentage of *H. harrisii* in Dc3 (22%) than in Dc2 (12%) or Dw3 (3–6.5%) was observed in NND-5030, but only one sample was productive in this study. *Myrtaceidites* spp. shows a decrease in the same drill hole; highest in Dw3 (11.5%–32.5%), decreasing through Dc2 (11%) and lower in Dc3 (3%). A slight decrease in gymnosperms from Dw4 (4%) into E1 (1%) occurs in NND-5028 but only one sample of Dw4 was analysed. Dc2 shows a high percent occurrence of proteaceous pollen (7.5%) when compared to E1 (5%) in NNA-5605. A high percentage of *Proteacidites* spp. may characterise Dc2, as 13% was also recorded in NNA-5510. It is similarly high in CD-1-779; with the proteaceous occurrence in E2 ranging from 2–2.5% compared to 6.5%–8% in Dc2, but E1 was barren in this location so a

stratigraphic boundary could not be assessed. Dc1 has a higher percentage of myrtaceous pollen (11–11.5%) compared to Dc2 (3%) in the same drill hole, but was not cored elsewhere in the cross section. Only a few samples of each of the D subunits were studied and further research may confirm the few trends seen in individual drill holes.

Table 7.11 Trends in percent occurrence of major pollen groups within the 'D' interval.

Strat. Unit	NND-5030	NND-5028	NNA-5605	NNA-5510	CD-1-779
			Haloragacidites harrisii		
Dc3	22				
Dc2	12				
Dw3	3–6.5				
			Myrtaceidites spp.		
Dc3	3				
Dc2	11				
Dc1					3
Dw3	11.5–32.5				11–11.5
			Total gymnosperm spp.		
E1		1			
Dw4		4			
			Proteacidites spp.		
E2					2–2.5
E1			5		barren
Dc2			7.5	13	6.5–8

7.2.4 Lithological palynomorph trends

The highest concentrations of *Haloragacidites harrisii* are observed in clay-rich to lignitic intervals (E2, Dc3) (Fig. 7.12 and Table 7.12). The percentages are not consistently high within these intervals, but similar abundances are not observed in the sandstone intervals (Dc2, Dw3). In NNA-5510, the percentage of *H. harrisii* in the E2 lignite is 9–14.5% compared to 1.5–7.5% in Dc2. For NND-5030, the clay-rich intervals E2 and Dc3 show a range in the occurrence of *H. harrisii* from 6.5–29.5%, compared to 3-12% in the sandstone units Dc2 and Dw3. CD-1-779 and NNA-5507 show a similar trend, but fewer samples of each interval were analysed in these drill holes. A single sample of E2 in CD-1-779 contained 14.5% *H. harrisii* in

the count, compared against a range of 4–9.5% for Dc2. For NNA-5507 10% *H. harrisii* was recorded in one sample from E2 and 1.5% in a single sample from Dw3. This trend is not consistent between the Ambassador and Princess uranium ore bodies, with NNA-5605, drilled through Princess, showing a fairly consistent presence of *H. harrisii* throughout all lithostratigraphic units intersected (12–18% in clay rich E3 and Dc1 and 13–18% in the sand units E1 and Dc2).

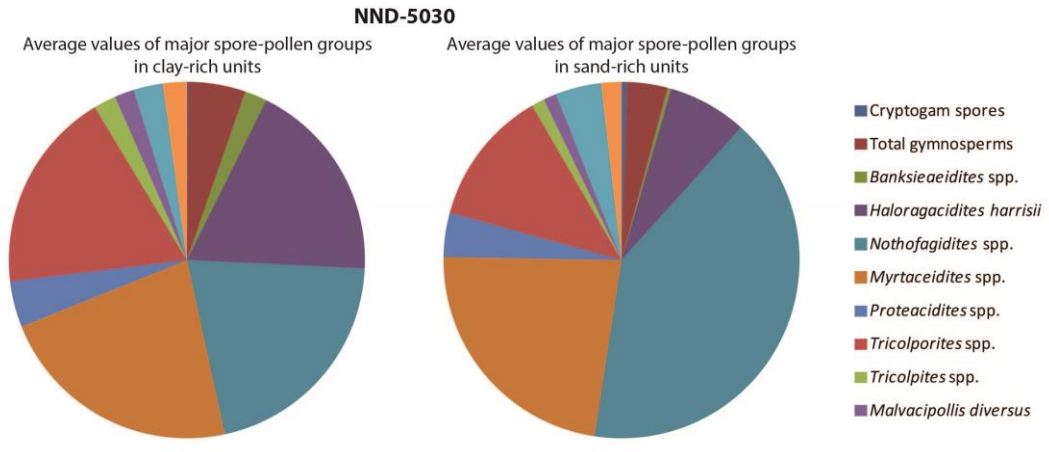


Fig. 7.12 Representative chart of lithological trends in palynomorph distribution. Drafted by averaging data from Table 7.3.

Table 7.12 Distribution of *Haloragacidites harrisii* in five drill holes. Blue highlights the clay-rich intervals and orange, the sand-rich.

Haloragacidites harrisii					
Strat. Unit	**NNA-5510**	**NND-5030**	**CD-1-779**	**NNA-5507**	**NNA-5605**
E3					18
E2	9–14.5	6.5–29.5	14.5	10	
E1					13–16.5
Dc3		22			
Dc2	1.5–7.5	12	4–9.5		18
Dc1					12–12.5
Dw3		3		1.5	

Where comparisons can be made between the clay-rich (Dc1, Dc3) and the sand-rich subunits of D (Dc2, Dw3), the presence of proteaceous pollen appears to be higher in the sandier intervals of D (Table 7.13). In NND-5030, the percent occurrence of *Proteacidites* spp. in the sand Dw3 is 7% of the count compared to Dc3 at 5%, though in Dc2 it is unusually low at 0.5%. In NNA-5605, proteaceous pollen in Dc2 is 7.5% of the count, slightly higher than in Dc1 at 4–6.5%. CD-1-779 only preserves

Dc2, but the percentage of proteaceous pollen ranges from 6.5–8%. Similarly, only Dw3 was sampled from NNA-5507 but the count contains 13% of species assigned to *Proteacidites* spp. These drill holes can be compared against others where the clay-rich intervals of D have been recorded, and proteaceous pollen ranges from 4–6.5%.

Table 7.13 Distribution of *Proteacidites* spp. in five drill holes. Blue highlights the clay-rich intervals and orange, the sand-rich.

Proteacidites spp.				
Strat. Unit	**NND-5030**	**NNA-5605**	**CD-1-779**	**NNA-5507**
Dc3	5			
Dc2	0.5	7.5	6.5–8	
Dc1		4–6.5		
Dw3	7			13

The distribution of major groups in the lignitic E2 unit in the diamond drill hole NND-5028 shows an interchange between pollen species assigned to *Haloragacidites harrisii*, *Myrtaceidites* spp. and *Nothofagidites* spp (Fig. 7.4). The percentage presence of both *H. harrisii* and *Nothofagidites* spp. in NND-5028 decrease as *Myrtaceidites* spp, increases. In this drill hole, *Tricolporites* spp. also increases as *Myrtaceidites* spp. increases. The lithology logged through E2 within this drill hole is fairly consistent except for a minor clayey sand interval between two lignitic sequences. This clayey sand interval aligns with the maximum percentage of *Myrtaceidites* spp. recorded for E2 in NND-5028.

The percent occurrence of the remaining major groups are fairly consistent, and do not change over lithological boundaries. However, some exceptions are associated with an individual sample within a unit. *Banksieaeidites* spp. ranges from 0–2.5% in most samples. Higher concentrations are seen in NND-5028 at 41.5 m (5%) and 45.8 m (8%), within the E2 interval. At 41.5 m only *Banksieaeidites arcuatus*, the Musgraveinae affiliate, is present. For the 45.8 m sample the *Banksia*-affiliates, *Banksieaeidites cooksonii* sp. nov. and *B. davidsonii* sp. nov., are dominant (3.5% each). A higher percent occurrence of *Banksieaeidite*s spp. is also noted for E2 in NNA-5510, with 5.5% in the 43–44 m sample and 4.5% in the 44–45 m sample. *Banksieaeidites cooksonii* occurs at 4.5% and 4% respectively, with *B. davidsonii* at

0.5% in the 44–45 m sample only. *Malvacipollis* spp. ranges from 0–2% in most samples, but there are several exceptions. The high occurrences in NND-5028 (4.5–18.5%) and CD-1-779 (14%) have been discussed previously, but peaks also occur in NND-5030 (4.5% at 42.2 m), NNA-5738 (4.5–7% from 49–53 m) and NND-5510 (3–4.5% from 43–45 m).

7.2.5 Distribution of individual species

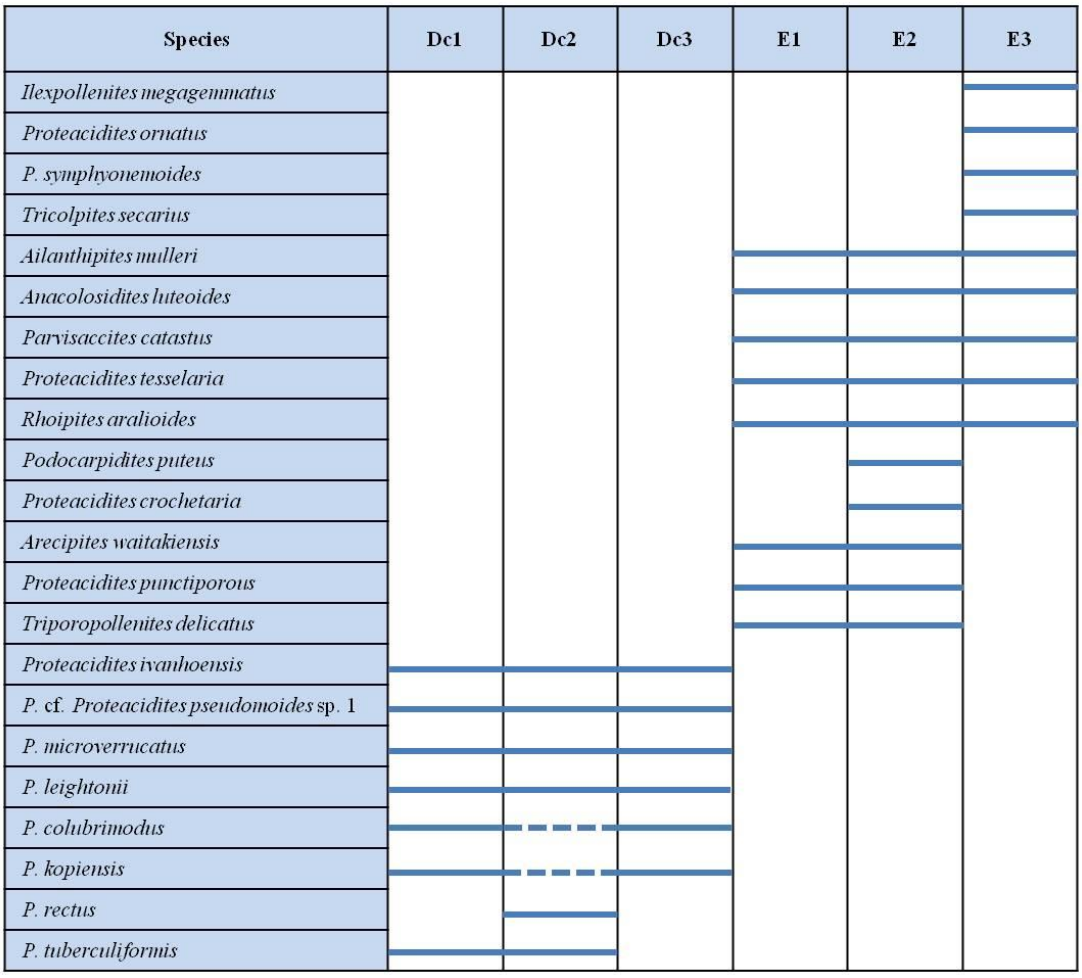


Fig. 7.13 Distribution of stratigraphically restricted pollen species at Mulga Rock

The distribution and ranges of individual species within the Mulga Rock sediments were studied to determine if palynostratigraphic markers were present for the major stratigraphical boundaries recognised by Vimy (Fig. 7.13). The most easily defined boundary is that between the major units, E and D, with the subunits less defined. Species restricted to and that occur throughout Unit E, include the gymnosperm

Parvisaccites catastus and the angiosperms *Ailanthipites mulleri, Anacolosidites luteoides, Proteacidites tesselaria* n.sp. and *Rhoipites aralioides.* This list is not inclusive of those species present only within subzones. Species constrained to E3, the uppermost carbonaceous unit, include *Ilexpollenites megagemmatus, Proteacidites ornatus, P. symphyonemoides* and *Tricolpites secarius.* Only two samples of E3 were processed and productive, thus only one or two specimens of the above were observed. Those species solely occurring in the E2 lignite are the gymnosperm *Podocarpidites puteus* and the angiosperm *Proteacidites crochetaria* n. sp. Species constrained to both the E2 and E1 intervals are *Proteacidites punctiporus, Triporopollenites delicatus* and *Arecipites waitakiensis*.

Species only found within interval D, not inclusive of those defining subzones, are *Proteacidites ivanhoensis, P.* cf. *P. pseudomoides* sp. 1, *P. microverrucatus* and *P. leightonii*. Two *Proteacidites* species occur only within the clay-rich subunits of Unit D (Dc3 and Dc1), *P. colubrimodus* and *P. kopiensis. Proteacidites rectus* has only been observed in subunit Dc2, and *P. tuberculiformis* only in Dc3 and Dc1.Many of the species of restricted distribution in the Mulga Rock flora, as listed above, are only rarely observed.

7.2.6 Percent occurrence of individual species in stratigraphic units

Changes were observed in the percent occurrence of individual species identified in the counts between different lithostratigraphic units in most of the drill holes studied, but these were not consistent over the entire cross section sampled. The major groups discussed in sections 7.2.1 to 7.2.4 included the species *Haloragacidites harrisii* and *Malvacipollis diversus* so these are not discussed here.

NNA-5605: The only significant change in the percentage of an individual species in this drill-hole was a smaller percentage of *Nothofagidites brachyspinulosus/incrassatus* in Unit D as whole, when compared to Unit E.

NNA-5738: Only two of the E subunits were sampled in this drill hole. The counts for subunit E1 recorded a lower percentage of *Podocarpidites ellipticus* than for E2.

NND-5077: Both *Lygistepollenites florinii* and *P. ellipticus* are, on average, lower in E1 than in E2, though the percentages in individual samples of E2 are variable. The percentage of *N. brachyspinulosus/incrassatus* is also higher in samples from interval E2.

NND-5028: Nothofagidites brachyspinulosus/incrassatus is higher in the E units, except for a decrease to the base of E1, than in Dws4.

NNA-5507: The percentages of both L. *florinii* and *P. ellipticus* are lower in Dw3, than in E1 and E2. A lower percent occurrence of *N. brachyspinulosus/incrassatus* was recorded for Dw3 and E1 than E2.

NND-5030: In contrast to the distribution of *N. brachyspinulosus/incrassatus* in other drill holes, the percentage changes little over the boundary between units D and E. An unusual peak of *Rhoipites angurium* was recorded for the Dc3 interval but was not observed elsewhere.

CD-1-779: The percentage presence of both *L. florinii* and *N. brachyspinulosus/incrassatus* were higher for E2 than either subunit E3 or unit D.

NNA-5510: A lower percentage of *L. florinii* and *P. ellipticus* occurred in Dc2, than in E2. A change in *N. brachyspinulosus/incrassatus* was again observed with the percentage presence of the species higher in E2 than in Dc2 for NNA-5510.

8. Discussion: implications of the Mulga Rock palynoflora for palynostratigraphy, palaeovegetation and depositional environment

This chapter includes the publication "C. L. Mack and L. A. Milne, 2015, Eocene palynology of the Mulga Rocks deposits, southern Gunbarrel Basin, Western Australia. *Alcheringa* **39 (4)**; 444–458". Additional information is drawn from the work completed, and species identified after the publication of this paper. These results are outlined in Chapters 5, 6 and 7, the interpretation of which further supports the conclusions of Mack and Milne (2015).

Mack and Milne (2015) discussed the palynological assemblages recovered from 23 samples in 10 drill holes, located in the Mulga Rock Project tenement in the southern Gunbarrel Basin of Western Australia. It reports the age and biostratigraphic correlation of the assemblages, and assesses the depositional environment and palaeovegetation. A brief comparison to palynological studies from elsewhere in southern Australia is given. The main conclusions of this paper are that the Mulga Rock assemblages are of late Eocene age, and that they represent a mosaic of vegetation communities that included a scleromorphic component. The sediments studied were deposited within a palaeochannel system hosting a swamp/floodplain environment.

An additional 55 productive samples were analysed for this thesis from eight drill holes, including further samples from CD-1-779 and NNA-5510 (with a few samples from these also included in the following paper). The additional information provided by the current study is outlined below, following the major headings outlined in the paper discussion.

8.1 Age and biostratigraphic correlation

Mack and Milne (2015) dated Energy and Minerals Australia's (now Vimy Resources) 'D' and 'E' intervals for the Mulga Rock project as late Eocene: "*The palynofloras studied from the Mulga Rocks site, recovered from lithological intervals 'E' and 'D', can be dated to the late Eocene based on the presence of* Anacolosidites

sectus *Stover & Partridge, 1973 and* Sapotaceoidaepollenites rotundus *Harris, 1972, which first occur in the late Eocene of the Gippsland Basin, and the co-occurrence of* Tricolpites incisus *Stover in Stover & Partridge, 1973,* Proteacidites adenanthoides *Cookson 1950,* P. crassus *Cookson, 1950 and* P. leightonii *Stover in Stover & Partridge, 1973. This agrees with Islam's (1983) correlation of lignite samples from Mulga Rocks with the Middle* Nothofagidites asperus *Zone. The Mulga Rocks assemblages are characteristically similar to the Murray Basin equivalent of the Middle* N. asperus *Zone based on the high diversity of* Proteacidites *spp. and the consistent presence of* Santalumidites cainozoicus *Cookson & Pike, 1954. Further evidence supporting a late Eocene age is the presence of* Proteacidites confragosus *Harris, 1972, which is restricted to the late Eocene in the Otway Basin, and occurs in samples throughout the Mulga Rocks section."*

No species that were of restricted age range in either the Gippsland Basin or the Murray Basin have been found limited to either unit D or E, indicating that the two units are of similar age. Several additional species were noted in the supplementary (subsequent to the paper) assemblages studied that first occur at the beginning of the Middle *N. asperus* Zone (Stover and Partridge 1973); *Aglaoreidia qualumis* Partridge in Stover and Partridge 1973, *Proteacidites stipplatus* Macphail and Truswell 1993, *Rhoipites sphaerica* Cookson 1947, *Proteacidites rectomarginis* Cookson 1950 and *Verrucosisporites cristatus* Partridge in Stover and Partridge 1973. *Rhoipites sphaerica* in particular, occurs in samples through intervals D and E. Further to the indicator species from the Gippsland Basin, *Tricolpites thomasii* Cookson and Pike 1954 was also recognised and indicates the base of the equivalent zone from the Murray Basin. The rarity of index species from the Gippsland Basin in the Murray Basin (Macphail 1999) led to the use of restricted species from elsewhere in Australia to constrain the Middle *N. asperus* Zone equivalent. These include *Proteacidites confragosus* and *P. tuberculatus.* Several proteaceous species that terminate within the Middle *N. asperus* Zone in the Gippsland Basin were also used to constrain the Murray Basin equivalent and are recognised in the Mulga Rock palynoflora; *Proteacidites leightonii*, *P. nasus* and *P. ornatus.* This confirms that the Mulga Rock assemblages can be dated as late Eocene based on the presence of pollen species throughout the section that best correlate to the Murray Basin Middle *Nothofagidites asperus* Zone equivalent (Macphail 1999).

Diachronism in spore-pollen species age ranges, outside of the Gippsland, Bass and Murray Basins for which standard zonation schemes are erected, has long been noted in the dating of palynofloras (e.g. Milne 1988, 1998, Macphail 1999). A similar assemblage to that recognised at Zanthus (Milne 1988) is reported from the Mulga Rock flora, with restricted species for several of the Gippsland Basin palynostratigraphic zones (Stover and Partridge 1973) co-occurring in the palynoassemblage (Fig. 8.1). Using this scheme alone gives a broad age range of middle Eocene to early Miocene.

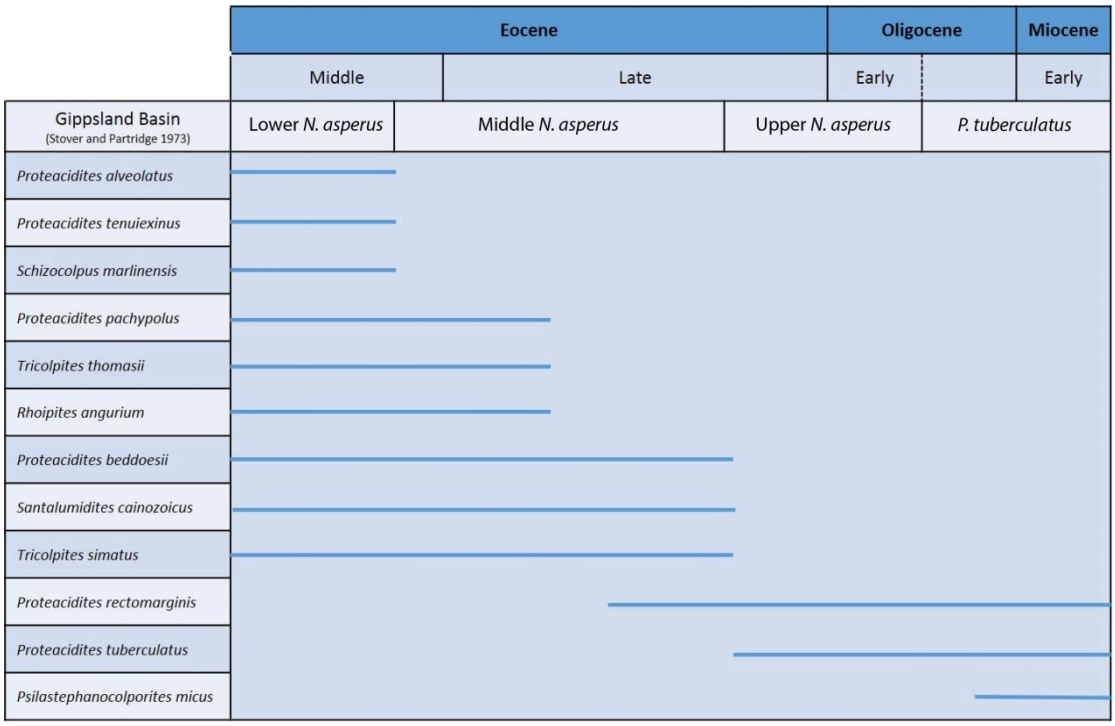


Fig. 8.1 Species that co-occur in Mulga Rock assemblages and their stratigraphic ranges in Stover and Partridge 1973, against the amended zonations of Partridge 1976.

8.2 Depositional environment

From Mack and Milne (2015): "*Palynomorphs present that can be aligned with extant taxa preferring riparian habitats include the parent plants of the spores* Cyathidites australis *Couper, 1953*, C. minor *Couper, 1953 and* Laevigatosporites ovatus *Wilson & Webster, 1946 and the pollen* Banksieaeidites arcuatus *Stover in Stover & Partridge, 1973*, Dacrycarpidites australiensis *Cookson & Pike, 1953*, Lygistepollenites florinii, Nothofagidites brachyspinulosis *(Cookson) Harris, 1965*

and N. emarcidus *(Cookson) Harris, 1965*. […] *Of most significance for the presence of a riparian environment is the prominence (up to 37.5%) of* Malvacipollis diversus *in some samples.* […] *Floodplain, sedgeland, swamp and salt marsh species were also recognized. These include* Sparganiaceaepollenites barungensis *Harris, 1972* [and …] Gleicheniidites *spp*. *Further evidence for the presence of riparian herb-dominated low/open vegetation at the depositional site is the presence of* Liliacidites *species* […].

The trends presented in Chapter 7 have implications for the palaeodepositional environment at Mulga Rock. Section 8.2.1 presents the depositional environments indicated by the lithostratigraphic units present along the studied transect, and presents an explanation for their distribution. Section 8.2.2 explains the distribution of palynomorphs within and between these stratigraphic units. While facies seem to be the prevalent cause of many of these trends, other explanations are offered.

8.2.1 Lithostratigraphy

All but one of the drill holes studied in the project are from the Ambassador ore body, with one (NNA-5605) from the Princess ore body. The drill holes are essentially situated along the length of the ore body, trending northeast to southwest, with NNA-5605 at the extreme northeast. The full extent of the Narnoo palaeovalley is not known, nor is the original direction of flow, so interpretation of the palaeoenvironment and the relationship between the sediments in the drill holes is difficult. A likely relationship between the stratigraphic units and their depositional environment is proposed (Table 8.1).

The ‘E’ unit of the Vimy stratigraphy can be interpreted to represent an overbank flow deposit in a floodplain adjacent to a meandering river (E1), subsequent deposition of sediment in a swamp environment within this floodplain (the lignite of E2), and the later infill of this swamp with clastic sediment (E3). E1 is present in all drill holes studied, ranging from 2–11 m thick.

Table 8.1 General characteristics and depositional processes forming the stratigraphic units at Mulga Rock, and the interpreted depositional setting.

Stratigraphic Units	General Characteristics	Depositional Processes	Depositional Setting
E3	Claystone, carbonaceous		Floodplain
E2	Lignite, siltstone and claystone	Preservation of large amounts of carbonaceous material	Swamp
E1	Carbonaceous sandstone Fining up	Decreasing current energy	Overbank (floodplain) deposit
Dc3	Carbonaceous claystone, oxidised at top	Migration of meander	Edge of floodplain
Dc2	Stacked packages of fining up sandstone to claystone	Cycles of deposition, accretion due to migration of meander	Point bar
Dc1	Limited distribution, lignite to carbonaceous claystone	Highly carbonaceous	Floodplain/swamp
Dw4	Grey claystone	Migration of meander	Edge of floodplain
Dw3	Fining up sandstone		Point bar
Dw1/2	Conglomerate		Ravinement surface

Overbank deposits, such as E1, occur when the volume of water input to a river exceeds the volume of the channel, first depositing coarser grained material and fining up as energy decreases into the floodplain (Nichols 2009). Unit E2 is present in all drill holes, except NNA-5605, ranging from 5–10 m thick. The E2 interval is highly carbonaceous and often lignitic, and is likely to represent deposition within a flood plain/swamp as the fine grained sediment indicates lower energy conditions. The presence of lignite indicates that the area was highly vegetated. The sediments included within the E2 unit are more lignitic to the northeast end of the studied cross-section (NNA-5738, NND-5077, NND-5028), becoming more clay-rich to the southwest. NNA-5605 is located within the Princess deposit to the north-east (approximately 2 km from the nearest drill hole, NNA-5738), and may be to the edge of the interpreted swamp, as the E2 lignite is missing from this drill hole. Unit E3 is absent from diamond core drilled by Vimy (NND-5077, NND-5028 and NND-5030),

and ranges from 2–8 m thick in the remaining drill holes. The absence of E3 in these drill holes is most likely due to the company's exploration focus on the E2 lignite, with the E3 unit either missed or above the oxidation boundary in these locations. The E3 unit may also be thicker in some drill holes, with the start of logging often within the interval.

The 'D' unit of Vimy's stratigraphy is mostly composed of coarser sandier units with minor clay intervals (Dc3, Dc1, and Dw4). The transition between fining-up sands to clays may be due to the migration of a meandering river channel, as the movement of the river course causes the top of the point bar (e.g. Dc2) to transition to the edge of the floodplain (e.g. Dc3). This produces packages of fining up sand, capped with finer grained sediments (Nichols 2009). Dc1 only occurs in NNA-5605; the drill hole located within the Princess deposit, and measures 6 m thick. The distance of this drill hole from the remainder of those in the study (Fig. 4.1) makes it difficult to assess the relationship of Dc1 to the rest of the system. Dc2 is thin to the north-east of the transect, ranging from 4 m in NNA-5605, NNA-5738 and thinning to 1 m in NND-5028. The Dc2 interval is absent in NNA-5507, before thickening from 4 m in NND-5030 to 26 m in CD-1-779. The Dc2 sand here is interpreted as a point bar within a meandering river (Table 8.1). Point bar deposits are fining up packages of sediment deposited on the inner banks of meandering rivers (Nichols 2009). The interpretation of channel sediments at this location correlates with the less lignitic nature of sediments assigned to E2 in these drill holes. Dc3 is present in NNA-5738, measuring 12 m in thickness. This is likely to represent a flood plain, similar to the environment of deposition for E1 and E3. The unit is then absent from NNA-5738, NND-5028, and NNA-5507. A significantly thinner interval of Dc3 is present in NND-5030 (3.5 m), through CD-1-779 (1 m) and thickening to 5 m in NNA-5510. The unit in NNA-5510 includes an isolated 2.5 m interval of sand in an otherwise fine-grained unit, representing a localised increase in energy in the system. This may be linked with increased sediment influx as water flow increased in through the palaeodrainage system, along pre-existing channels associated with the southeastern end of the transect (Fig. 7.2).

The 'Dw'-affixed sub units represent another package of channel sediments with associated clay units. Dw1 and Dw2 have previously been interpreted as ravinement

surfaces (Fig. 3.4 and 7.1). Dw3 is only present in NND-5028 and drill holes to the south-west of it. It is absent from CD-1-779, but the end of hole is within the overlying Dw4 unit. The thickness of Dw3 ranges from 5–14 m and is interpreted to be an older point bar than Dc2. The clay unit, Dw4, shows a similar distribution to Dc3; it is thicker to the northeast (in NNA-5605 at 3.5 m thick and in NNA-5738 at 5 m thick), thinning to 1 m in NND-5028 and is absent in NNA-5507. This correlates with the distribution of floodplain sediments from other units, with channel sediments again to the south-west end of the transect.

8.2.2 Palynomorph trends

The trends in major groups and individual species discussed in Chapter 7 may be related to one or more factors that include the depositional environment, climate and soil fertility, and the migration of meandering river channels and the resulting facies changes within the Narnoo palaeovalley (Figure 8.2). Further research is required to map the channel(s) and assess the movements of the associated environments, but the results of this study indicate a relationship between percent occurrence and the distribution of species to the proposed environments and the influence of the palaeochannel.

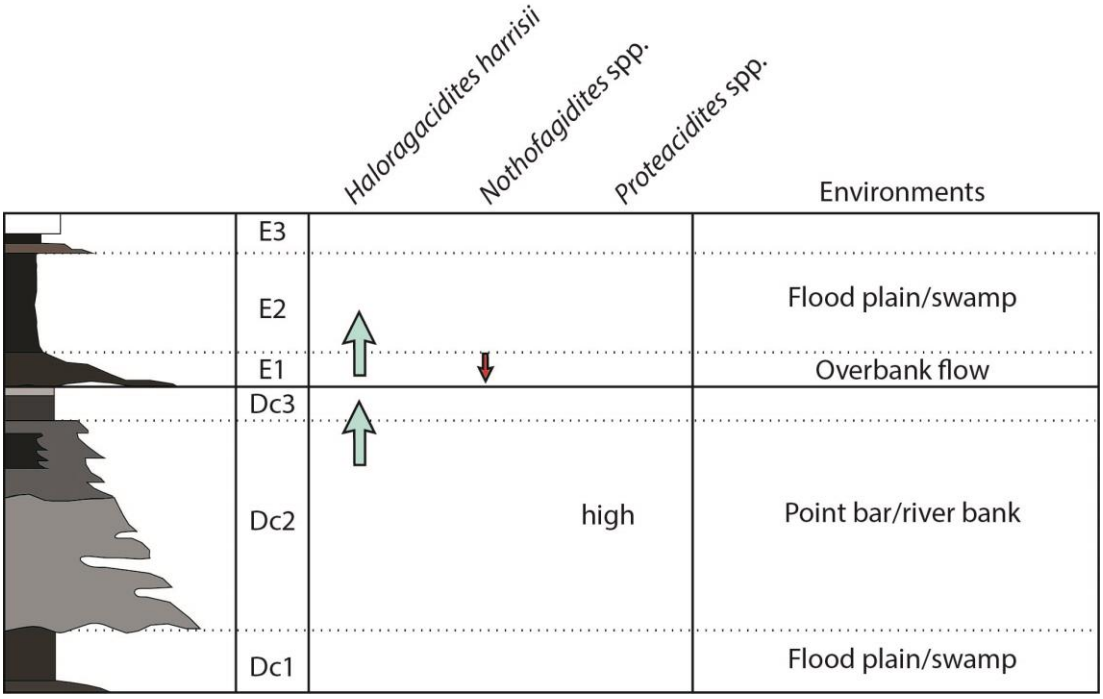


Fig. 8.2 Environments indicated by changes in percent occurrence of major pollen groups over stratigraphic boundaries in some drill holes.

Haloragacidites harrisii shows an association with clay-rich units; increasing from the sand-rich sub-unit E1 into the E2 lignite and highest in the clay unit Dc3, compared to the sand Dc2. The association of large amounts of *H. harrisii* with the clay-rich units indicates that it is likely within, or near to, the local vegetation of the floodplain and swamp environments represented by Dc3 and E2 respectively. Extant Casuarinaceae are wind pollinated, and produce large amounts of pollen, so could contribute these percentages from the hinterland. This also makes the distribution of *H. harrisii* over the entire section difficult to explain. The only occurrence of Dc1, in NNA-5605, contains a lower concentration of *H. harrisii* than is present in Dc2. As percent occurrence decreases with distance from the source plants using wind vectors, the trends in NNA-5605 could be related to the location of stands of plants producing *H. harrisii.*

Proteacidites spp. occur in the largest percentages in the sandstone units of D, when compared against the more clay-rich units (Dc1, Dc3, and Dw4). The sand rich units, Dc2 and Dw3, have been interpreted to be point bars within a river system. Extant species of Proteaceae are generally pollinated by insect/animal vectors and the pollen produced by these plants is rare in sediments by comparison with pollen from wind-pollinated plants. It is likely that similar pollination processes were occurring in the Eocene and that the proteaceous pollen in the Mulga Rock sediments can be interpreted to be produced by plants growing in the local area. Soil fertility decreases with sand content, and this may indicate that these species were adjusted to a nutrient-poor soil like most extant Proteaceae.

An interchange in dominance between *Myrtaceidites* spp./*Tricolporites* spp.-rich assemblages and *Nothofagidites* spp./*Haloragacidites harrisii*-rich assemblages, occurs most clearly within the E2 lignite in NND-5028 (Fig. 7.4. and 8.3), and likely represents a shift in the palaeovegetation within the study area. *Nothofagidites* spp. have been associated with wetter environments (Martin 1984). Modern Casuarinaceae, to which *Haloragacidites harrisii* is aligned, has a broad distribution and the fossil forms are likely to represent a number of species/genera with different ecological preferences. The association of *H. harrisii* with *Nothofagidites* spp. in NND-5028 means it is likely to prefer a wetter environment. Both *Nothofagidites*

spp. and *H. harrisii* are likely to have been prolific pollen producers (based on the pollen production and dispersal of their nearest living relatives [NLRs]). It is difficult to say with any certainty where the plants producing these pollen types were in relation to the study area; they could have been upstream, in the hinterland or growing locally. In the Murray Basin of southeastern Australia, *Myrtaceidites* spp. have been linked with drier environments (Martin 1984). Myrtaceous species today are both animal and wind pollinated. Extant plants producing tricolporate pollen are mostly herbaceous or shrubs, and are rarely wind pollinated. These two pollen groups most likely represent the local plant community. The interchange of dominance between *Myrtaceidites* spp./*Tricolporites* spp. and *Nothofagidites* spp./*Haloragacidites* spp. could be linked to climate, seasonal changes, a shift in the channel morphology or possibly, changes to the vegetation as a result of fire. The exact nature of this relationship requires further study.

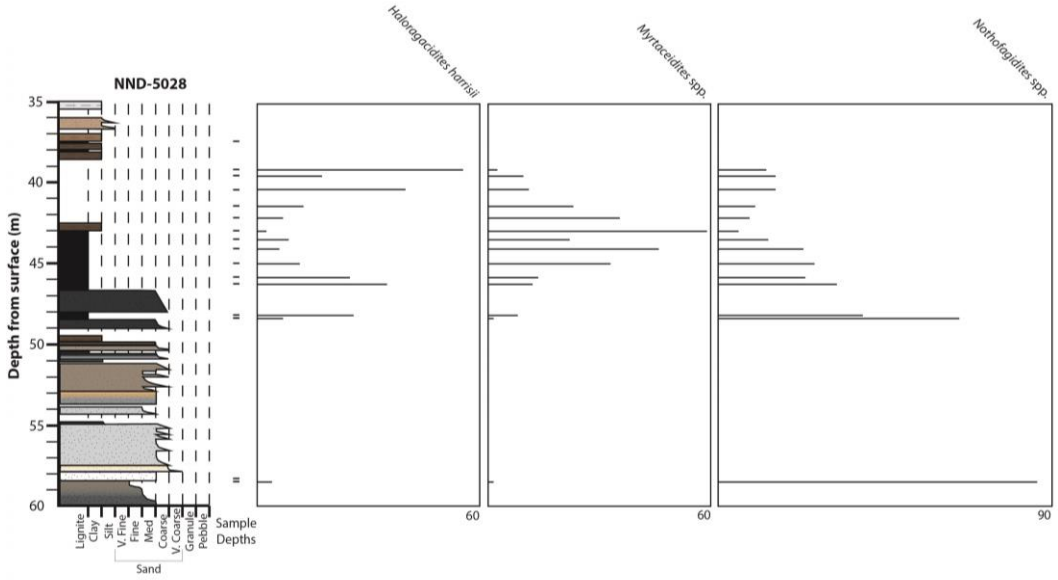


Fig. 8.3 Interchange in dominance between *Myrtaceidites* spp. and *Haloragacidites harrisii/ Nothofagidites* spp. in borehole NND-5028.

Changes in the percent occurrence of pollen groups over the E1/E2 boundary is likely related to the change from the initial outflow of water from the meandering river system (E1) to the formation of an associated floodplain/swamp (E2). As before, the higher percent occurrence of *H. harrisii* is associated with those units that can be related to deposition within a swamp environment. The decreasing percent occurrence of *Nothofagidites* spp. towards the top of the E1 unit (e.g. in NND-5077 and NND-5028) may be due to decreasing input from channel flow. *Nothofagus* is a

prolific pollen producer, and species today that grow near river banks often extend branches over the water, the pollen being dispersed in significant amounts by the water current as well as by wind.

In summary, the changes in the dominance of major pollen groups and individual species, and their relationship to the lithology, suggests a mosaic of plant communities that may be the result of changes in the morphology of a meandering river and its associated floodplain, and the influence of other factors including climate variability, seasonality, or soil quality. It is most likely a combination of these factors that influence the composition of the palynomorph assemblages at the Mulga Rock site.

8.3 Palaeovegetation

From Mack and Milne (2015): "[…] *the Mulga Rocks assemblages indicate that a mosaic of woodland communities with a distinct sclerophyll component existed at or near the Mulga Rocks site. Rainforest species, such as* Nothofagidites spp.*, were probably localized upstream or in the hinterland, and at times contributed significant amounts of pollen via wind and water. The diversity of the Mulga Rocks palynoassemblages, even in samples containing abundant* Nothofagidites*, and the known scarcity of other species in extant* Nothofagus *forests provide further evidence that the palynoflora at Mulga Rocks is unlikely to represent a mesothermal* Nothofagus*-dominated rainforest at the depositional site*."

Interpreting palaeovegetation relies on determining an affinity between fossil pollen grains and the pollen produced by plants growing today. Often this is only possible to a family or generic level, which means that plant habits can range from trees to shrubs in numerous environments. Where possible, the interpretation of the Mulga Rock flora has relied on generic identifications and has described the full range of environments interpretable from these alignments (also in 8.5 Addendum).

Further contributing to the indications of a sclerophyll flora at Mulga Rock, is the presence of several species of myrtaceous pollen (Plate 10 M–O and Plate 25 U, V)

with morphology resembling that produced by modern eucalypts. The presence of these species, including the newly described *Myrtaceidites corymbioides,* and their dominance, is likely to represent a sclerophyllous nature to the vegetation at or close to the site.

A relationship between percent occurrence of *Myrtaceidites* spp. and *Nothofagidites* spp./*Haloragacidites* spp. was identified in Section 8.2 (Fig. 8.3). The use of wind pollination by species of all three of these groups, and the large amounts each produces, makes it difficult to determine whether these species were present in the local or regional plant communities. However, the preferred environments of these species today, indicate that this may be due to the shifting of drier vs. wetter environments and the adjustment of sclerophyll vs. mesophyll floras at the site.

Pollen species with morphology similar to extant Conospermeae were already identified as part of the Mulga Rock palynoflora in Mack and Milne (2015). Subsequently, *Proteacidites punctiporus* Macphail and Truswell 1993 has been identified in the Mulga Rock palynoflora. This species has been aligned with the Proteaceae genus *Stirlingia* Endl. and is similarly indicative of a sclerophyllous flora. A total of 70 species that can be aligned with Proteaceae, both previously described and new, are present within the palynoassemblages at Mulga Rock. The high diversity of the genera is irreconcilable with the presence of a *Nothofagus*-dominated mesothermal rainforest, and concurs with the assessments of Hos (1975) and Milne (1988, 1998). The extant *Nothofagus* forests on the southern island of New Zealand contain little other than ferns and epiphytic mosses and lichens (Dawson 1988) and, in the context of the diverse Mulga Rock assemblages, *Nothofagus* is unlikely to have been prominent in the local vegetation. However, as the Mulga Rock flora is dominated by *Brassopora*-type pollen with some *Fuscospora* (rather than *Fuscospora* dominated as described by Dawson), it is possible that the *Nothofagus*-forest possessed a richer understorey similar to that seen in New Guinea and New Caledonia. Yet, in the case of those proteaceous species aligned with species occupying sclerophyll environments today; it is still unlikely that those were forming a rainforest understorey. Proteaceous pollen is also more likely to be representative of the local flora, as most extant Proteaceae use insect/animal vectors. The pollen they produce is relatively large and unlikely to be easily dispersed by wind.

8.4 Comparison with other southern Australian assemblages

A brief assessment of the major pollen and spore groups present at Mulga Rock, and a comparison to the south-eastern Gippsland and Murray basins and south-western Bremer and Eucla basins, is discussed in Mack and Milne (2015): *"The Mulga Rocks assemblages differ from the majority of late Eocene palynoassemblages studied in southeastern Australia. They most closely resemble the* Proteacidites*-rich assemblages studied in the Eucla* (Milne 1988) *and Bremer (Stover & Partridge 1982) basins of WA, but differ in the high concentrations of* Myrtaceidites *spp., which reach a relative abundance of up to 54.5% in this study. The Mulga Rocks site, located inland from Zanthus-6, lacks the marine influence recognized by Milne (1988)."*

"*The high diversity and relative abundance of* Proteacidites *spp. (1–24.5%) differ from assemblages in the Murray and Gippsland basins where* Nothofagidites *spp. dominance has been taken as evidence for* Nothofagus*-dominated mesothermal rainforests (Macphail* et al. *1994). Although* Nothofagidites *spp. are abundant in some of the Mulga Rocks samples, high percentages of* Myrtaceidites *spp. in some samples, and a common and highly diverse proteaceous component, indicate a more sclerophyllous woodland character to the vegetation in the depositional area than that reported for coeval southeastern Australian basins*." General assemblage differences are of most accuracy when considering differences in palynofloras between southeastern and southwestern Australia, due to the recognised diachronism in the distributions of individual species.

Of interest is how the distributions of individual species change between those at Mulga Rock and more southern Western Australian assemblages, namely those studied in the former Bremer Basin (Stover and Partridge 1982) and the Eucla Basin at Zanthus (Milne 1988). The percent occurrences of either major groups or of individual species were not included in Stover and Partridge (1982). Individual species not occurring at Mulga Rock but present in Stover and Partridge's assemblage are numerous, and similarly, many species that occur at the study site do not occur in the former Bremer Basin assemblage. Of most significance is the

increased diversity of proteaceous pollen at Mulga Rock over the Bremer Basin. A total of 25 proteaceous species were assigned to *Propylipollis, Proteacidites* or *Triporopollenites* by Stover and Partridge (1982), compared to 78 at Mulga Rock.

In contrast, the Zanthus palynoflora recorded a total of 60 proteaceous species, 50 of which are shared with the Mulga Rock assemblages. An additional 10 that had been previously described, as well as 8 new *Proteacidites* species, were recognised from Mulga Rock. The Mulga Rock assemblages also include a lower diversity of gymnosperms at a lower percent occurrence. At Zanthus, a minimum of seven gymnosperm species were present in individual samples, reaching a maximum of 15, and ranged in percent occurrence from 2.8 to 27.2%. A total of 7 gymnosperm species were recorded in Mulga Rock samples, with percent occurrence ranging from 0.5 to 15.5%. In particular, four species of *Phyllocladidites* and *Podocarpidites* were recorded at Zanthus, compared to one and two respectively at Mulga Rock. Also of note, not only are percentages of myrtaceous pollen higher at Mulga Rock, but the amount and number of species with an affinity to eucalypts are also higher. In addition to *Myrtaceidites eucalyptoides,* a new species, *M. corymbioides*, has been described here that has similarities to pollen produced by *Corymbia*. The percent occurrence of *M. eucalyptoides* ranges from 0.5 to 10% in the Mulga Rock palynoflora, compared to 0.4 to 0.8% at Zanthus. The Zanthus palynoflora also did not include large *Banksieaeidites* spp. (as described in Chapter 9).

8.5 Addendum

As suggested by the examiners, a table listing the known modern affinities of the species in the palynoflora at Mulga Rock has been constructed (Appendix 12). The suggestion that a broader range of vegetation types than those reported in Mack and Milne (2015) were likely present in the Mulga Rock area, is addressed below. The affinities listed in Appendix 12 suggest that the range of plant communities that likely contributed to the Mulga Rock palynoflora likely included the end points of dry sclerophyll heath and woodland, wet and dry sclerophyll forests with some *Nothofagus* forest in the region. It should be noted that the set of species present in a sclerophyllous forest and woodland and those in mesothermal *Nothofagus* dominated

rainforests are not mutually exclusive to either, and that many extant rainforest plants also occur in the understorey of wet sclerophyll forests. Several species of *Eucalyptus* (Myrtaceae), along with *Allocasuarina torulosa* (Casuarinaceae) and *Banksia aquilonia* (Proteaceae) occur in wet sclerophyll forest in northern Queensland today. Fossil pollen species in the Mulga Rock flora have been aligned with the same families (*Myrtaceidites* spp., *Haloragacidites harrisii* and *Banksieaeidites* spp. respectively) and may have formed part of a similar forest type near Mulga Rock.

The high percentage of angiosperms in the pollen counts, relative to that of spores and gymnosperms, supports Mack and Milne's (2015) tenet that the local vegetation did not resemble the *Nothofagus* forests of today, as those in New Caledonia and New Guinea in particular also include a significant presence of conifers (Araucariaceae, Podocarpaceae). Species aligned to these families were either not present or rare in the Mulga Rock samples studied.

As there are currently no established means of distinguishing *Casuarina* from *Gymnostoma* pollen the ecological distribution of both in the modern flora can be used to interpret the appreciable counts of *Haloragacidites harrisii* in Mulga Rock samples. One *Gymnostoma* leaf fossil was recognised at the site (Paull and Hill 2010), but with the range of morphologies assigned to *H. harrisii* it is unlikely that this was the sole Casuarinaceae species existing at or near the site. *Casuarina*-type leaves first appear in the fossil record in Early Eocene sediments at Mt Hotham (Christophel 1980), so it is possible that species closer to that of modern day *Casuarina* were present at Mulga Rock. *Haloragacidites harrisii* is consistently present throughout the samples studied, and probably occupied most of the environments listed for Casuarinaceae in Mack and Milne (2015); from river banks, to more open sections of rainforest to sclerophyllous woodland.

Proteaceae as a family occupy a wide range of environments with most occurring as trees to woody shrubs. A number of proteaceous pollen species in the Mulga Rock flora could only be assigned at the family level and may represent anything from heath shrubs to rainforest trees. Other *Proteacidites* species present had affinities with extant Proteaceae growing solely in dry forest types, woodland, savannah and

heath; *Proteacidites adenanthoides* (*Adenanthos*), *P. annularis* (*Xylomelum*), *P. cirritulis* (*Petrophile*) and *P. punctiporus* (*Stirlingia*) (Milne 1998, Dodson and Macphail 2007). Others occupy a range of environments; with *P. symphyonemoides* (*Symphionema)* indicating wet peaty heaths to drier heath or *P. pseudomoides* (*Lomatia*) a range including rainforest, through open woodland to exposed heath. The NLRs of *Proteacidites* species listed in Appendix 12 do include species that currently occupy rainforest, but most also occur in a broader range of environments than just rainforest today. Half of the recognised proteaceous species can be aligned with extant genera that currently only occupy dry forest types, woodland and heath. Extant *Beauprea* occupy photophile forests on rainforest perimeters and imply a vegetation type near Mulga Rock where plants were more spaced apart, such as woodlands today.

The main group of Myrtaceae pollen present, that assigned to *Myrtaceidites mesonesus/parvus*, has been aligned with many extant myrtaceous genera and could represent anything from closed forest through wet sclerophyll to sclerophyllous woodlands and heath as suggested here. Those samples where *Eucalypt* types (such as *Myrtaceidites eucalyptoides*) were present in addition to *M. mesonesus/parvus*, and in association with proteaceous pollen with sclerophyllous NLRs, were interpreted to represent sclerophyll forest and woodland, and this interpretation stands. However, other samples with similarly high Myrtaceae (but possibly lacking the sclerophyllous input) may also represent rainforest, wet sclerophyll, or a mosaic of the two (Martin 1987). Martin (1987) also noted that the fire history of a region would impact the interpretation of Myrtaceae-dominated vegetation. Charcoal has been observed in palynological slides from Mulga Rock, but its presence is an ongoing study. Many of the species aligned with *Myrtaceidites mesonesus/parvus* are also known to grow in semi-swamp forests in New Zealand (Martin 1993), and the deposition of lignite and lignitic clays in the Narnoo palaeovalley certainly indicates that swamps were part of the local depositional environment.

Mack and Milne (2015) interpreted a mosaic of woodland communities with a distinct sclerophyll component at or near the Mulga Rock site with rainforest species, such as *Nothofagidites* spp., probably localized upstream or in the hinterland. This can now be extended to include wet sclerophyll, based on the broad range of

ecological tolerances of extant Myrtaceae genera aligned with *Myrtaceidites mesonesus/parvus. Haloragacidites harrisii* and *Banksia* spp. also potentially indicate this type of forest, though only a single species of *Banksia* occupies this environment in Queensland. Other types of rainforest are unlikely, with all samples studied dominated by *Nothofagidites* spp., *Myrtaceidites* spp., or *Haloragacidites harrisii*. Casuarinaceae dominated samples likely represent river bank communities, with both *Gymnostoma* and *Casuarina* today forming woodlands in these environments.

Alcheringa: An Australasian Journal of Palaeontology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/talc20

Eocene palynology of the Mulga Rocks deposits, southern Gunbarrel Basin, Western Australia

Charlotte L. Mack & Lynne A. Milne

Published online: 13 Apr 2015.

Eocene palynology of the Mulga Rocks deposits, southern Gunbarrel Basin, Western Australia

CHARLOTTE L. MACK and LYNNE A. MILNE

Mack, C.L. & Milne, L.A., XX.XXXX. 2015. Eocene palynology of the Mulga Rocks deposits, southern Gunbarrel Basin, Western Australia. *Alcheringa 39*, xxx–xxx. ISSN 0311-5518

Late Eocene palynomorph assemblages have been recovered from carbonaceous sediments within a tenement centred on the Mulga Rocks uranium deposits, currently under exploration by Energy and Minerals Australia. The Mulga Rocks deposits occur in a palaeovalley incised into rocks of the Cretaceous southern Gunbarrel Basin, and the underlying Neoproterozoic to Late Devonian southern Officer Basin, Western Australia. The palynomorph assemblages recovered from the Mulga Rocks deposits most closely resemble the Middle *Nothofagidites asperus* Zone equivalent of the Murray Basin. Many of the species recovered, and the abundance and diversity at which they are present, are considerably different from most of the southeastern Australian palynoassemblages of similar age. Common in the assemblages are species belonging to *Nothofagus*, Casuarinaceae, Myrtaceae and Picrodendraceae. Proteaceous species are diverse, with *Banksia* affiliates being prominent. Of most significance are assemblages dominated by *Myrtaceidites* species, which also contain affiliates of *Petrophile* and *Xylomelum* that occur in modern heathland, woodland and dry sclerophyll forests. The prominence of these taxa, and their co-occurrence, suggests that sclerophylly, at present linked closely with xeromorphy and now ubiquitous in the vegetation of Western Australia, was present in the late Eocene of southern Australia and suggests that at that time this trait may have been more prevalent than previously interpreted.

Charlotte Mack [charlotte.mack@postgrad.curtin.edu.au] and Lynne Milne [l.milne@curtin.edu.au], Department of Applied Geology, Curtin University GPO Box U1987, Perth, WA 6845, Australia. *Received 4.7.2014; revised 11.2.2015; accepted 19.2.2015.*

Key words: scleromorphy, xeromorphy, Cenozoic, Proteaceae, Myrtaceae, spore-pollen.

CENOZOIC palynostratigraphy in Western Australia (WA) has long relied on standard biostratigraphic zones established for southeastern Australian basins (e.g., Stover & Partridge 1973, Partridge 1976) and an assumption that the *Nothofagus*-dominated mesothermal rainforest interpreted for these basins also occurred throughout southern WA at the same time (Bint 1981, Hos 1975, Macphail *et al*. 1994, Macphail 2007). Although significant differences below the family level have been noted between the macrofloras of southwest and southeastern Australia (Scriven *et al*. 1995), a similar difference can now be recognized in the palynofloras. Studies of Cenozoic palynoassemblages in southwest and central southern Australia have been conducted in the Bremer and Eucla basins (Bint 1981, Hos 1975, Stover & Partridge 1982, Milne 1988) and for palaeochannels incised into the Yilgarn Block (Balme & Churchill 1959, Waterhouse *et al*. 1994). The construction of a palynostratigraphic framework for WA Cenozoic strata has been limited by sediment accumulation in small basins in a patchwork fashion. Additionally, no currently known sections in WA appear to span more than one southeastern Australian palynozone. Lack of a palynostratigraphic scheme for WA has required that the schemes established in eastern Australian Cenozoic basins be extrapolated for strata studied in the southwest. Hos (1975), reporting an Eocene assemblage from the Bremer Basin, argued it closely mirrored palynofloras of southeastern Australia but he remarked on the unusual amount of Proteaceae pollen present. Milne (1988) reported that in the late Eocene Zanthus-6 assemblages, in the western Eucla Basin, index species from several southeastern Australian zones co-occurred in the samples. Milne (1988, 1998) also identified significant numbers of Proteaceae and the common presence of species related to *Petrophile* Knight and *Xylomelum* Sm. These species today occupy a significantly different environment to the *Nothofagus*-dominated mesothermal rainforest represented in the Paleogene of southeastern Australia. Macrofossil floras in WA also show a sclerophyllous element with diverse Proteaceae, including *Banksia* L.f., and Myrtaceae Juss. having thick leaves and a lack of rainforest adaptations, such as drip tips. This has been recognized for several Cenozoic leaf floras studied in southern WA (Hill & Merrifield 1993, McLoughlin & Hill 1996, Carpenter & Pole 1995) and by the recent description of a *Banksia* species with xeromorphic characters (Carpenter *et al*. 2014). Of particular interest is the Myrtaceae-dominated West Dale macroflora from the Wheatbelt of WA (Hill & Merrifield 1993). To date, a palynoflora with similar myrtacean dominance has not been discovered but an analogue may be present within

http://dx.doi.org/10.1080/03115518.2015.1022090

the assemblages recovered from sediments in the present study.

In the Officer and Gunbarrel basin area, few palynological studies have been completed other than exploration reports on less than 10 samples. Many of these reports were aimed at defining the Cretaceous/Paleogene boundary, with most samples dated as Early Cretaceous rather than Cenozoic, and a few samples dated as Carboniferous (Powis 1979). Islam (1983) dated four samples from cuttings taken from the Mulga Rocks lignitic interval and determined that the majority of palynomorphs were long-ranging forms, but constrained three of these samples to the Middle *Nothofagidites asperus* Zone of Stover & Partridge (1973) and Partridge (1976). Compounding difficulties arising from the study of the few Cenozoic samples is the high frequency of barren or indeterminate samples, and those where contamination due to drilling mud circulation has been deemed too significant to obtain meaningful results. This study describes the palynomorph assemblages recovered from exploratory drill core at Mulga Rocks and discusses these in relation to current biostratigraphic zones, depositional environments of the sediments, the palaeovegetation it represents, and the relationship with assemblages of similar age in southern Australia.

Geology and stratigraphy

The studied area covers the Mulga Rocks exploration site, approximately 250 km east-northeast of Kalgoorlie, within the southwestern Gunbarrel Basin (Fig. 1). A significant interval of lignite contains a rich palynoflora in addition to being the host rock of a potentially economic sedimentary uranium deposit. The lignites were deposited within a palaeochannel incised into the Permo-Carboniferous Paterson Formation (Hocking pers. comm.). Fewster (1999) informally described the study area as a new basin, the 'Narnoo Basin', named after the adjacent Geological Survey of Western Australia map sheet. However, Douglas *et al.* (2003) suggested that instead, the study area is indicative of a palaeochannel formed by crustal upwarping along the eastern margin of the Yilgarn Craton prior to the late Eocene, which may account for the significant thickness of the sediments present. Here we refer to it as the 'Narnoo palaeovalley' based on work undertaken by de Broekert & Sandiford (2005) on similar features on the Yilgarn Craton. Exploration drilling has enabled the definition of the palaeovalley over a distance of 100 km at 5–15 km wide. In the west, the palaeovalley connects with the modern drainage of Lake Raeside and Ponton Creek and continues into the Queen Victoria Springs Fauna and Flora Reserve in the south.

The stratigraphy (Fig. 2) of the Narnoo palaeovalley comprises Cenozoic and Cretaceous sedimentary successions, overlying the late Palaeozoic Paterson Formation, Mesozoic sediments of the Gunbarrel Basin and, locally, the Precambrian crystalline rocks of the Yilgarn Craton and Albany-Fraser Province (Fewster 1999). As Cenozoic sediments do not fall within the current established stratigraphy for the Gunbarrel Basin, an informal stratigraphic scheme and nomenclature have been adapted by Energy and Minerals Australia (EMA) to identify 12 sedimentary units of differing lithological characteristics. These subdivisions are delimited by

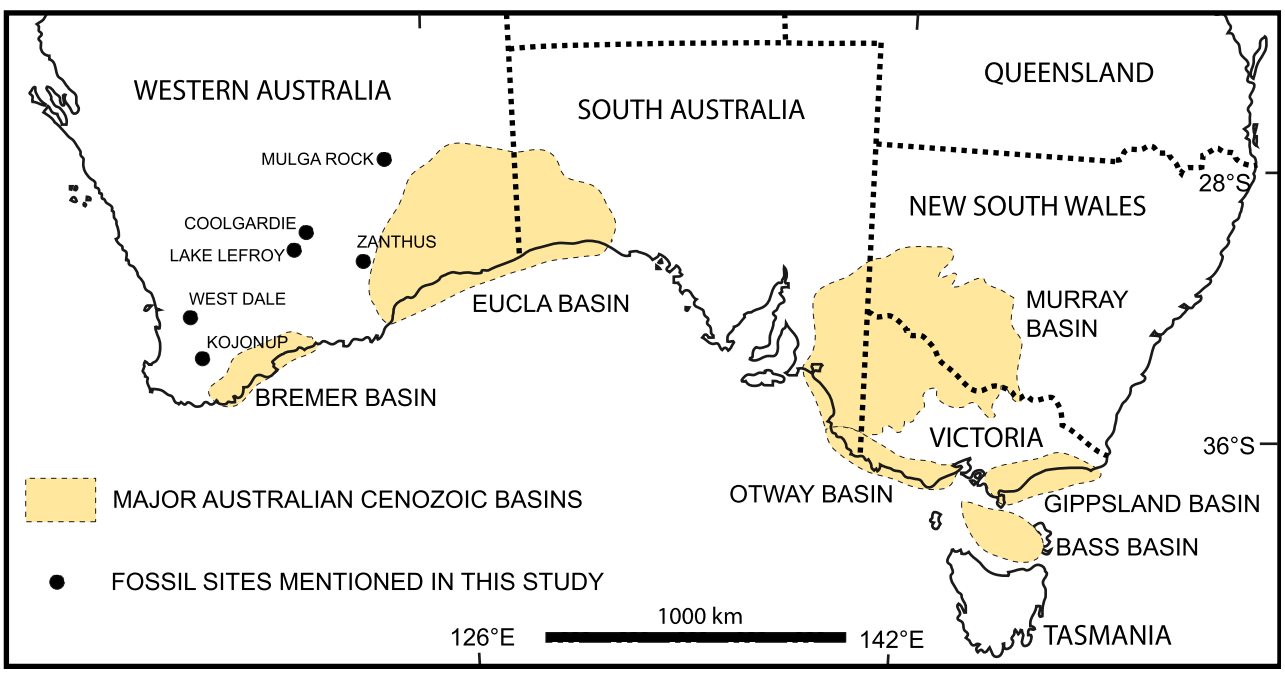


Fig 1. Location map of studies mentioned (adapted from Milne, 1997).

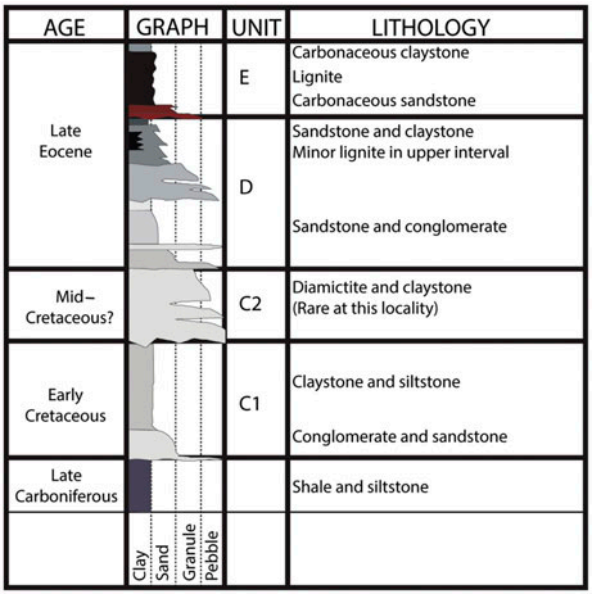


Fig 2. Stratigraphic column for the Mulga Rocks deposits.

unconformable contacts correlated by Fewster (1999). An alphanumeric scheme has been used by EMA to differentiate the stratigraphic units. Further studies to refine the ages and lithologies of sedimentary packages are required before the lithostratigraphic nomenclature can be formalized. This study focuses on material of Eocene age from units 'E' and 'D' (Fig. 2).

'Unit E' (Fig. 2) is recognized as equivalent to the middle to late Eocene Pidinga Formation of the western Eucla Basin and palaeochannel sediments from the southeast Yilgarn Block (Fewster 1999). Unit E includes carbonaceous claystones, lignites and intermediate lignitic claystones. A lenticular granulestone grading to coarse- to fine-grained, carbonaceous, oily and locally pyritic sandstone marks the base of the unit.

'Unit D' (Fig. 2) was dated as middle Eocene by Islam (1983) from a sample obtained from drillhole CD-1-1 in the interval 67–68 m. This unit was correlated with the Hampton Sandstone in the Eucla Basin, palaeochannels in the southeast region of the Yilgarn Craton and the Lampe Formation in the Officer Basin by Fewster (1999). Samples for the present study were acquired only from the uppermost section of the unit, a lenticular conglomerate grading to dark grey, coarse- to fine-grained, carbonaceous sandstone.

Materials and methods

Twenty-three samples of lignite and carbonaceous clays and sands were palynologically analysed from core extracted during drilling exploration of the Mulga Rocks deposits. Samples were collected from historical diamond drilling conducted by the Power and Nuclear Corporation of Japan (PNC) between 1979 and 1986, and from a December 2010 air-core program completed by EMA. Samples were processed at Curtin University according to a method adapted from Phipps & Playford (1984) that employs a HCl–HF–HCl–HNO_3–NaOH technique. Samples (5–20 g) were crushed and heated in HCl to remove carbonates and treated with HF to remove silicates. The extraneous organic material remaining was then oxidized with HNO_3, followed by NaOH to break up the organic acids produced. At each stage, the residue was rinsed three times in distilled water. Strew slides were mounted in the plastic medium 'Eukitt', examined with an OLYMPUS-BX51 transmitted light biological microscope and photomicrographs were taken with an OLYMPUS-P71 digital camera. Preparations containing illustrated specimens are registered (Appendix A) and stored with the Geological Survey of Western Australia. References to taxon authorities for extant plants are available at the International Plant Names Index: http://www.ipni.org.

Results

The composition of the Mulga Rocks palynoassemblages (Table 1, Figs 3, 4) is typical of middle and late Eocene suites. The assemblages are collectively dominated by *Haloragacidites harrisii* (Couper) Harris in Mildenhall & Harris, 1971 (1.5–53.5%), *Myrtaceidites* spp. (0–54.5%) and *Nothofagidites* spp. (1.5–61%), with a high diversity of proteaceous species (0.5–24.5%) in the majority of samples regardless of the dominant taxa. Gymnosperm pollen, mostly *Lygistepollenites florinii* (Cookson & Pike) Stover & Evans, 1973 (0–5%) and *Podocarpidites* spp. (0–4%), most significantly *P. ellipticus* Cookson ex Couper, 1953, are present in small quantities (0–2%). *Malvacipollis diversus* Harris, 1972 (0–37.5%) and tricolporate pollen (1–15%), mostly as *Rhoipites angurium* (Partridge) Pocknall & Mildenhall, 1984 and *R. minutiformis* Truswell & Owen, 1988, are present in significant quantities within some samples.

Several distinctly different palynoassemblages, based on the relative occurrence of dominant taxa, can be loosely tied to variations in the lithostratigraphic units described by Fewster (1999). However, a further study of the extent of the facies relationship is required and will be the subject of future study. Of note, at 41 m in drillhole CD-1-1360 is an assemblage characterized by a dominance of *Myrtaceidites* spp. (54.5%) and a high percentage of *Banksieaeidites* spp. (8.5%). High numbers of *Myrtaceidites* spp. (Fig. 3Q–U) in NNA-5025 at 73 m and CD-1-763 at 45.3 m are associated with the *Petrophile* (*Proteacidites cirritulis* Milne, 1988; Fig. 4F) and *Xylomelum* (*P. annularis* Cookson 1950; Fig. 4I) affiliates, comprising 25% and 78% respectively of the Proteaceae pollen present in the samples. In each of these samples, the *Nothofagidites* spp. (Fig. 3V–A1) percentages do not exceed 26.5% and are as low as 1.5% in CD-1-1360.

Drill program	CD																			OF	NNA	
Well	1			409			481			779	763			1360	1485		52	5025	5510			
Depth (m)	35.1	40	67	31.1	34.8	41	45	39	41	42.2	43.3	81	45.3	55	65	72.9	41	39	40.7	86	73	75	79	
Lithology	C	LC	LC	C	LC	LC	C	LC	LC	LC	LC	C/FS	LC	LC	LC	FS	LC	C	C	FS	C	LC	LC/FS	
Cryptogam spores	1	0.5	2.5		2		6	0.5	2	0.5	1	1.5	1.5			2.5				3.5	2	0.5		
Gymnosperms																								
Podocarpidites spp.	1		2	1		0.5	1.5		4		2	1	1.5	0.5	0.5	0.5	0.5	0.5	1	3	0.5	0.5		
Lygistepollenites florinii	1	1	2		1				5		3	1	4	2					3.5		2	0.5		
Other spp.		0.5		0.5		3			2.5		1.5		1	0.5	0.5		3		0.5			3.5		
Angiosperms																								
Banksieaeidites spp.	0.5	2	2	0.5	4.5	8.5		2	0.5	1	1			3.5		2	8.5			3		2	2.5	
Haloragacidites harrisii	23.5	7.5	11	53.5	31	8.5	30	32.5	13	20.5	9	5.5	15	15.5	19	5	8.5	19	41.5	4	2	1.5	7.5	
Nothofagidites spp.	31.5	53.5	26	12	12.5	30.5	20.5	46	37	61	51	37.5	26.5	57.5	31	39.5	1.5	52.5	19.5	44.5	18	43.5	42.5	
Myrtaceidites spp.	3	12	25		22.5	50	2	2.5	18.5	0.5	20	33	33.5	8.5	2.5	34.5	50	12	5.5	22	54.5	13	21	
Proteaceae spp. (*Banksia*)	6.5	10.5	7		9.5	1	1	2.5	2	6.5	3.5	7.5	5	3.5	24.5	7.5	1	7	6	10.5	6	13	12.5	
Tricolporate spp.	2.5	8	6	1.5	2	11	1.5	4.5	5.5	1.5	2.5	6	3.5	1	1.5	2	11	4	1	3.5	9	15	7.5	
Tricolpites spp.	0.5							0.5				1				1		0.5	0.5	0.5	0.5	0.5		
Malvacipollis diversus	11.5		0.5	22.5	12.5	0.5	37.5	6.5	3.5	6	0.5	1	3.5	1	2		0.5		17			0.5	0.5	
Other spp.	17.5	4.5	16	8.5	2.5	15.5	0	2.5	6.5	2.5	5	5	5	6.5	18	5.5	15.5	4.5	4	5.5	5.5	6	6	

Table 1. Relative abundances of major spore-pollen groups in the studied cores. CD data from PNC core; OF and NNA from EMA drilling programs. C = clay; LC = lignitic clay; FS = fine sand.

Discussion

Age and biostratigraphic correlation

The assemblages recovered from the two lithological intervals (Fig. 2) examined over the entire stratigraphical section contain species that can be aligned with the Middle *Nothofagidites asperus* Zone assemblages in the Gippsland Basin as defined by Stover & Partridge (1973) and Partridge (1976), and its equivalent zone in the Murray Basin (Macphail 1999).

The palynofloras studied from the Mulga Rocks site, recovered from lithological intervals 'E' and 'D' (Fig. 2), can be dated to the late Eocene based on the presence of *Anacolosidites sectus* Stover & Partridge, 1973 (Fig. 3A4, 3A5) and *Sapotaceoidaepollenites rotundus* Harris, 1972, which first occur in the late Eocene of the Gippsland Basin, and the co-occurrence of *Triolpites incisus* Stover in Stover & Partridge, 1973 (Fig. 3A6, 3A7), *Proteacidites adenanthoides* Cookson 1950, *P. crassus* Cookson, 1950 (Fig. 4N) and *P. leightonii* Stover in Stover & Partridge, 1973. This agrees with Islam's (1983) correlation of lignite samples from Mulga Rocks with the Middle *Nothofagidites asperus* Zone. The Mulga Rocks assemblages are characteristically similar to the Murray Basin equivalent of the Middle *N. asperus* Zone based on the high diversity of *Proteacidites* spp. and the consistent presence of *Santalumidites cainozoicus* Cookson & Pike, 1954 (Fig. 3A2, 3A3). Further evidence supporting a late Eocene age is the presence of *Proteacidites confragosus* Harris, 1972 (Fig. 4S), which is restricted to the late Eocene in the Otway Basin, and occurs in samples throughout the Mulga Rocks section.

Stover & Partridge (1982) recognized the boundary between the Lower *N. asperus* Zone and the Middle *N. asperus* Zone as occurring either at the base of the late Eocene or within the late middle Eocene. Partridge (2006) aligned the base of the latter zone with the middle to late middle Eocene boundary, with the zone terminating by the end of the epoch. Macphail (1999) aligned the equivalent Murray Basin zone with the late Eocene. The Mulga Rocks assemblages are best aligned with the Murray Basin palynomorph suites of late Eocene age.

Depositional environment

The predominantly lignitic/carbonaceous clay and sand lithology of the studied samples indicates that much of the sedimentation occurred within a palaeochannel system hosting a swamp/floodplain environment. Palynomorphs present that can be aligned with extant taxa preferring riparian habitats include the parent plants of the spores *Cyathidites australis* Couper, 1953, *C. minor* Couper, 1953 and *Laevigatisporites ovatus* Wilson & Webster, 1946 (Fig. 3A), and the pollen *Banksieaeidites arcuatus* Stover in Stover & Partridge,

1973, *Dacrycarpidites australiensis* Cookson & Pike, 1953 (Fig. 3C), *Lygistepollenites florinii* (Fig. 3D, E), *Nothofagidites brachyspinulosis* (Cookson) Harris, 1965 and *N. emarcidus* (Cookson) Harris, 1965. Other than *Nothofagidites*, these species occur only in relatively small numbers. The sporadic abundance of *Nothofagidites* species within the Mulga Rocks assemblages may also be indicative of depositional environments upstream. Extant *Nothofagus* Blume species have a tendency to extend their lower branches across water when located adjacent to streams and lakes, allowing for significant dispersal of pollen by both water and air (Milne pers. observ.). Of most significance for the presence of a riparian environment is the prominence (up to 37.5%) of *Malvacipollis diversus* in some samples. Martin (1974) affiliated the species with *Dissilaria baloghoides* F. Muell. ex Baill, a species that today grows in scrubby vegetation along watercourses.

Floodplain, sedgeland, swamp and salt marsh species were also recognized. These include *Sparganiaceaepollenites barungensis* Harris, 1972, which may be related to extant Sparganiaceae, a class of burr reed now extinct on the Australian mainland, or *Typha* L., a sedge commonly known as bulrush (Harris 1972). Similarly, *Gleicheniidites* species may be affiliated with gleicheniaceous ground ferns within these environments. Further evidence for the presence of riparian herb-dominated low/open vegetation at the depositional site is the presence of *Liliacidites* species within the same assemblages.

Palaeovegetation

The relationship of fossil pollen to extant species allows for a general assessment of the palaeovegetation, but no exact analogue for the Mulga Rocks assemblage exists in the modern vegetation of Australia, or elsewhere. The pollen species with particular implications for interpreting the palaeovegetation of Mulga Rocks include *Myrtaceidites* (Myrtaceae), *Proteacidites* (Proteaceae), *Haloragacidites harrisii* (Casuarinaceae R. Br. = the she-oak family), *Nothofagidites* (*Nothofagus*) and *Dacrycarpidites* [*Dacrycarpus* (Endlicher) de Laubenfels and *Dacrydium* Lamb.]. Previous palynological studies (Hos 1975, Stover & Partridge 1982, Macphail *et al*. 1994) have inferred that *Nothofagus*-dominated mesothermal rainforest was present in southern WA in the Eocene. However, in many cases, this broad interpretation does not fit the palynoassemblages recovered from specific sites (Milne 1988, Al-Shawareb 2009). Some Mulga Rocks assemblages in particular show a dominance of *Myrtaceidites* and a diverse array of *Proteacidites* that indicate a distinctly sclerophyllous component of the palaeovegetation and the likely existence of heathland, woodland and/or sclerophyll forest at or near the depositional site.

Myrtaceae affiliates are dominant in some Mulga Rocks assemblages and include the *M. mesonesus–parvus* complex Cookson & Pike, 1954, *Myrtaceidites eucalyptoides* Cookson & Pike, 1954 and several undescribed species. The *Myrtaceidites mesonesus–parvus* complex has been very broadly aligned to several extant genera. *Myrtaceidites mesonesus* has been aligned with *Eucalyptus* (Cookson & Pike 1954, Martin 1973, Thornhill & Macphail 2012) and *M. parvus* currently has an unknown affinity but resembles pollen produced by *Baeckea* L., *Tristania* R. Br. (Martin 1978), *Kunzea* Rchb. and *Leptospermum* Forst. & G. Forst (Truswell 1983) that today occupy eucalypt forests to woodlands and heathlands (Beadle 1981). *Myrtaceidites eucalyptoides* is allied with modern *Eucalyptus* L'Hér. (Cookson & Pike 1954, Martin 1973). At present, *Eucalyptus* is absent from the rainforest associations remaining within Australia, but does occur in special habitats at rainforest margins or in mixed forests in these environments. Modern Myrtaceae occupy a variety of environments in Australia, including open sclerophyll (eucalypt) forest, arid and semi-arid shrublands and rainforest (Martin 1992). Martin (1992) recognized that it is mostly sclerophyll or open forests that show a dominance of *Eucalyptus* and/or *Casuarina* L. in Australia at present.

The Mulga Rocks lignite, like samples studied at Zanthus by Milne (1988, 1997, 1998) contains numerous species of Proteaceae, many of which can be affiliated with taxa that today occupy sclerophyllous and xerophyllous communities. The Mulga Rocks assemblage contains 34 identified species and more than 38 unidentified forms. *Proteacidites cirritulis* and *P. carobelindiae* have been allied to the Conospermeae genus *Petrophile* (Milne 1998). All but six of the more than 60 *Petrophile* species occur in WA in heathland and woodlands on well-drained granitic soil or sandy soil over laterite. In eastern Australia, *Petrophile* occur on rocky sandstone areas supporting heathland and dry sclerophyll forests. *Proteacidites annularis* is affiliated to the grevilleoid genus *Xylomelum* (Milne 1994), which today has only two species in WA and three on the eastern seaboard. All, including *X. scottianum* F. Muell., which occurs in northern Queensland, prefer sandy soils in heathland, woodland (Wrigley & Fagg 1989) and open forests (Foreman 1995). Two previously undescribed species of *Banksia* affiliates, *Banksieaeidites* spp. A and B (Fig. 4B–D) are also recognized in significant percentages in combination with *B. arcuatus* (up to 8.5%). These proteaceous genera, allied above with the fossil taxa, today are endemic to temperate Australia. If the ecological tolerances of these nearest living relatives (NLRs) have changed little since the late Eocene, then the presence of these proteaceous fossil species indicate sclerophyll communities akin to heathland, woodland and/or dry sclerophyll forests.

Evidence for a warm temperate rainforest is sparse in that most affiliates of the fossil morphotypes that can be aligned to this vegetation type have a much wider present-day ecological tolerance. *Haloragacidites harrisii* is affiliated with Casuarinaceae of unknown generic affinity (Macphail 2007). Commonly known as she-oaks, six *Casuarina*, 58 *Allocasuarina* L.A.S. Johnson and one *Gymnostoma* L. A. S Johnson species occur in Australia today. The Australian species, *G. australianum* L. A. S. Johnson, has a restricted distribution in the warm wet Daintree rainforest of north-eastern Queensland. It is ecologically versatile in that it usually grows in open, sunny gaps in the rainforest, in habitats that range from lowlands to uplands and including river banks to mountain tops (Prider & Christophel 2000). Not all *Gymnostoma* spp. are strictly rainforest species. In New Caledonia, *G. nobile* (Whitmore) L. A. S. Johnson is reported to occur in habitats ranging from heathland to forest (Johnson 1982), and in Papua New Guinea, *G. papuanum* (S. Moore) L. A. S. Johnson, occurs on the border of mixed forest and eucalypt savannah and is dispersed throughout savannah and grassland (Paijmans 1976). Although a leaf resembling *Gymnostoma* has been recovered from Mulga Rocks (Paull & Hill 2010), *H. harrisii* contains a range of morphotypes and it is likely that more than simply an affiliate of *G. australianum* was present at the site. The Mulga Rocks assemblage probably contains affiliates of various extinct *Gymnostoma*, *Casuarina* and *Allocasuarina* that today are widespread in Australia as components of sclerophyllous communities (Scriven & Hill 1995) ranging from open forest to sandy beach environments.

Several Mulga Rocks palynoassemblages contain relatively high percentages of *Malvacipollis diversus* (up to 37.5%). Although the current taxonomic status of *Malvacipollis diversus* is ambiguous and likely inclusive of several species, the majority of grains studied by Martin (1974) were affiliated with *Austrobuxus swainii* (Beuzev. & C.T.White) Airy Shaw and *Dissilaria baloghoides*, both of which belong to the Picrodendraceae (previously part of Euphorbiaceae Juss.). Both of these species currently reach the size of timber-producing trees in southeast Queensland and northeast NSW. *Austrobuxus swainii* in particular is a rainforest tree, but has a preference towards less fertile, sedimentary-based soils within these communities (Floyd 1989). *Dissilaria baloghoides* grows in dry rainforest, and is associated with scrubby vegetation along watercourses.

The presence of *Nothofagus*-allied pollen in Paleogene sediments has long been interpreted to represent a warm temperate rainforest that dominated the vegetation of the southern half of Australia, including WA (Hos 1975, Macphail *et al*. 1994). However, the fossil pollen species *Nothofagidites* comprises a wider range of morphologies than the extant *Nothofagus* pollen to which they are aligned (Dettmann *et al*. 1990). Thirty percent of *Nothofagidites* species lack an extant species to which they can be correlated. In addition, a high proportion of those that have been allied to modern species are not entirely analogous, so it is difficult to rely solely upon the modern ecological tolerances of *Nothofagus* to interpret the palaeovegetation of the Mulga Rocks site.

The majority of *Nothofagidites* spp. at Mulga Rocks were allied with modern producers of *Brassospora* by Dettmann *et al*. (1990), who also noted that *N. heterus*, which is here included in a series with *N. emarcidus* based on their alignment to the *brassii*-type, has no modern counterpart. *Nothofagidites* spp. is variably present at Mulga Rocks, ranging from as low as 1.5% to 60%. The 60% value, however, is not considered direct evidence of *Nothofagus*-dominated forests. Palynoassemblages at Anglesea contain percentages of *Nothofagidites*, aligned to *Brassospora*, of up to 50 or 60% in upper Eocene strata, but no *Nothofagus*-type leaves are present in the associated macrofossil assemblage (Hill 1990). Truswell (1993) noted that this may indicate that *Nothofagus* was a canopy dominant away from the forest edges. That extant *Brassospora* are less competitive at exposed forest edges due to a lower tolerance of temperature extremes, is well documented (Read *et al*. 1990). The 42 cuticle taxa recovered by Paull & Hill (2010) from Mulga Rocks sediments also did not include leaves of *Nothofagus*-type.

In the large cool temperate *Nothofagus* forests of the South Island of New Zealand, there are in many cases very few other species present aside from ferns and epiphytic mosses and lichens (Dawson 1988). The percentage presence of spores in the Mulga Rocks assemblages is relatively low, ranging from 0 to 4%. This evidence, together with the high diversity of the Mulga Rocks palynoassemblage, is indicative that the *Nothofagus* stands were generally not prominent in the vicinity of the depositional site.

Pollen species that can be aligned to *Dacrycarpus* and *Dacrydium*, which are now wholly extinct in Australia, such as *Dacrycarpidites australiensis*, may indicate a cool to warm temperate rainforest similar to those these genera now occupy in New Zealand. However, such species are only present in very low percentages at Mulga Rocks. Carpenter *et al*. (2014) noted that pollen affiliated with *Dacrycarpus* and *Dacrydium* was present in sediments as young as Pliocene age in south-western Australia, persisting as climates changed to seasonally dry and even after aridity was noted to be prevalent across much of Australia in the Miocene.

The presence of proteaceous species in assemblages dominated by Myrtaceae is strong circumstantial evidence for woody communities (Dodson & Macphail 2004). In the Mulga Rocks assemblage, there is a high diversity of proteaceous species (72 species identified to date). This contrasts with previous assumptions that the *Nothofagus*-dominated forests were consistent across

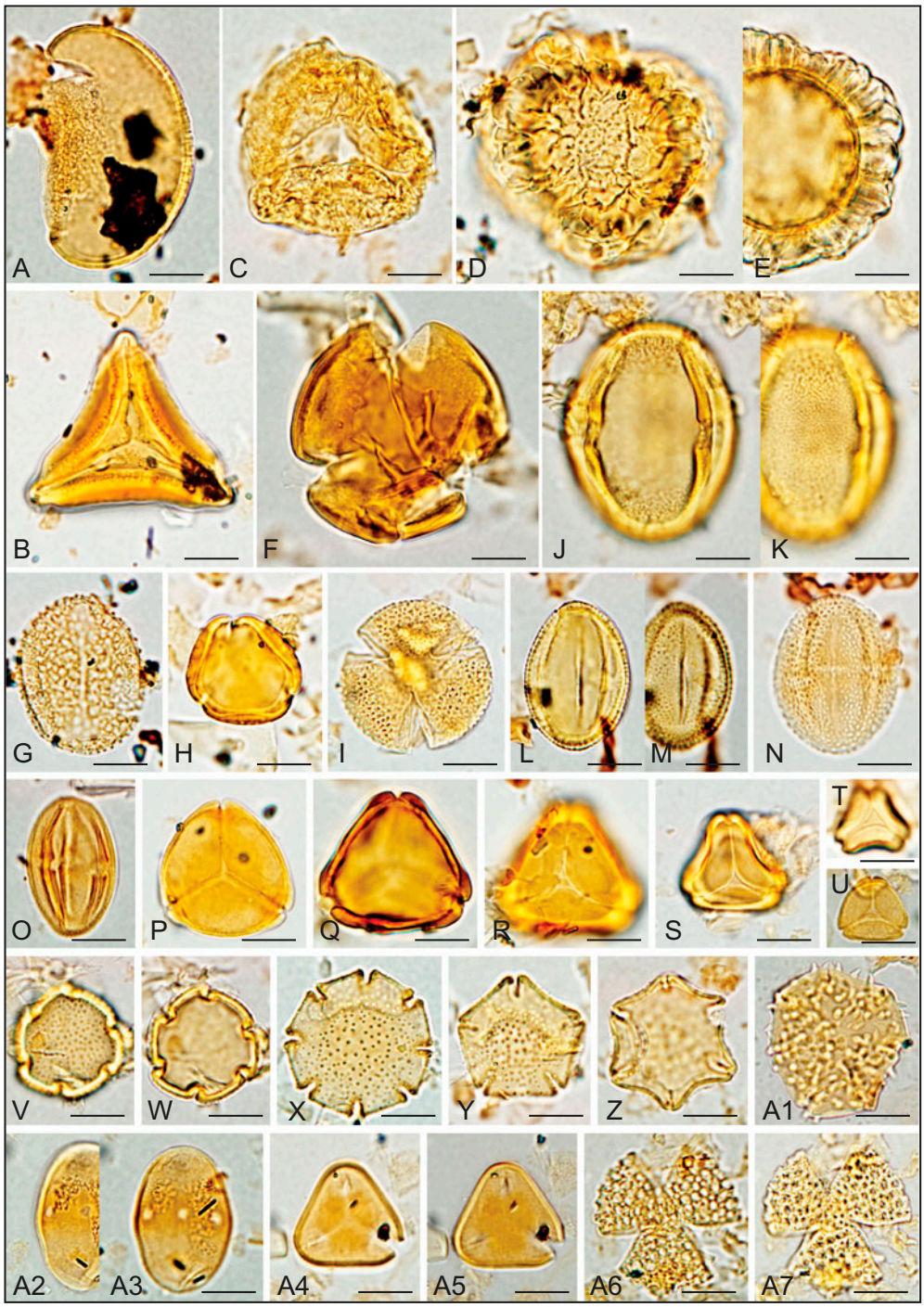


Fig 3. **A–A7,** Palynomorphs from the Mulga Rocks deposits. **A–B,** Cryptogam spores; **A,** *Laevigatosporites ovatus* Wilson & Webster, 1946; **B,** *Gleicheniidites circinidites* (Cookson) Dettmann, 1963. **C–D,** Gymnosperm pollen; **C,** *Dacrycarpidites australiensis* Cookson & Pike, 1953; **D–E,** *Lygistepollenites florinii* (Cookson & Pike) Stover & Evans, 1973, high and median focus respectively. **F–O,** Angiosperm pollen; **F,** *Tricolporites adelaidensis* Harris ex Stover & Partridge, 1982; **G,** *Liliacidites aviemorensis* McIntyre, 1968; **H,** *Tricolporites leuros* Partridge, 1973; **I,** *Rhoipites alveolatus* (Couper) Pocknall & Crosbie, 1982; **J–K,** *Tricolporites scabratus* Harris, 1965, median focus and high focus respectively; **L–M,** *Rhoipites angurium* (Partridge) Pocknall & Mildenhall, 1984, median focus and low focus respectively; **N,** *Rhoipites goulburnensis* Truswell & Owen, 1988; **O,** *Ailanthipites paenestriatus* (Stover) Milne, 1988. **P–U,** *Myrtaceidites* pollen; **P,** *Myrtaceidites* sp. 1; **Q–R,** *Myrtaceidites* sp. 2 median focus and low focus respectively; **S,** *M. eucalyptoides* Cookson & Pike, 1954; **T,** *M. eucalyptoides* different grain; **U,** *M. mesonesus* Cookson & Pike, 1954. **V–A1,** *Nothofagidites* pollen; **V–W,** *N. brachyspinulosis/incrassataus* (Cookson) Harris, 1965/Cookson, 1959, high focus and median focus respectively; **X,** *N. emarcidus/heterus* (Cookson) Harris, 1965/(Cookson) Stover & Evans, 1973; **Y,** *N. emarcidus heterus* (Cookson) Harris, 1965/(Cookson) Stover & Evans, 1973; **Z,** *N. falcatus* (Cookson) Hekel, 1972; **A1,** *N. spinosus* (Couper) Mildenhall & Pocknall, 1989. **A2–A3,** *Santalumidites cainozoicus* Cookson & Pike, 1954, median and high focus respectively. **A4–A5,** *Anacolosidites sectus* Stover & Partridge, 1973, high and median focus respectively. **A6–A7,** *Tricolpites incisus* Stover in Stover & Partridge, 1973, high and low focus respectively. Scale bars = 10 μm.

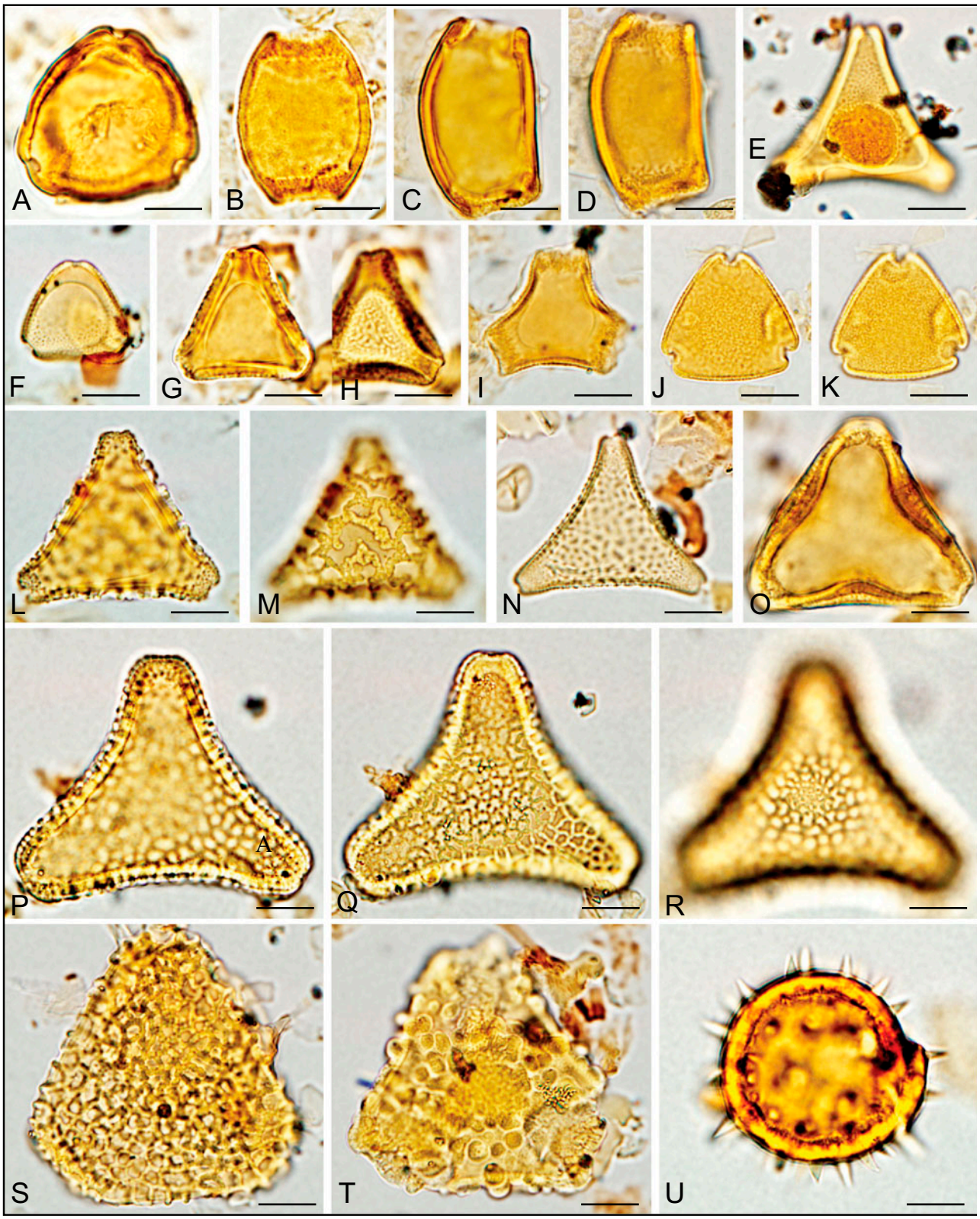


Fig 4. **A–U,** Angiosperm pollen; **A,** *Haloragacidites harrisii* (Couper) Harris in Mildenhall & Harris, 1971; **B–D,** *Banksieaeidites* pollen. **B,** *Banksieaeidites* sp. 1, high and median focus respectively; **C–D,** *Banksieaeidites* sp. 2; **E–T,** *Proteacidites* species; **E,** *P. pachypolus* Cookson & Pike, 1954; **F,** *P. cirritulis* Milne, 1988; **G–H,** *P. obscurus* Cookson, 1950, median and high focus respectively; **I,** *P. annularis* Cookson, 1950; **J–K,** *P. carobelindiae* Milne, 1998; **L–M,** *P. reticulatus* Cookson, 1950, median and high focus respectively; **N,** *P. crassus* Cookson, 1950; **O,** *P. bremerensis* Stover & Partridge, 1973; **P–R,** *P. nasus* Truswell & Owen, 1988, median, low and high focus respectively; **S,** *P. confragosus* Harris, 1972; **T,** *P. cumulus* Stover & Partridge, 1982; **U,** *Malvacipollis diversus* Harris, 1972. Scale bars = 10 μm.

both the east and west of southern Australia (Hos 1975, Macphail *et al*. 1994, Macphail 2007). Instead, the Mulga Rocks assemblages indicate that a mosaic of woodland communities with a distinct sclerophyll component existed at or near the Mulga Rocks site. Rainforest species, such as *Nothofagidites* spp., were probably localized upstream or in the hinterland, and at times contributed significant amounts of pollen via wind and water. The diversity of the Mulga Rocks palynoassemblages, even in samples containing abundant *Nothofagidites*, and the known scarcity of other species in extant *Nothofagus* forests provide further evidence that the palynoflora at Mulga Rocks is unlikely to represent a mesothermal *Nothofagus*-dominated rainforest at the depositional site.

Comparison with other southern Australian assemblages

The Mulga Rocks assemblages differ from the majority of late Eocene palynoassemblages studied in southeastern Australia. They most closely resemble the *Proteacidites*-rich assemblages studied in the Eucla (Milne 1988) and Bremer (Stover & Partridge 1982) basins of WA, but differ in the high concentrations of *Myrtaceidites* spp., which reach a relative abundance of up to 54.5% in this study. The Mulga Rocks site, located inland from Zanthus-6, lacks the marine influence recognized by Milne (1988). Whether the Mulga Rocks deposits are the result of fluvial deposition within an incised palaeovalley or deposition within an isolated basin as suggested by Fewster (1999) requires further study.

The high diversity and relative abundance of *Proteacidites* spp. (1–24.5%) differ from assemblages in the Murray and Gippsland basins where *Nothofagidites* spp. dominance has been taken as evidence for *Nothofagus*-dominated mesothermal rainforests (Macphail *et al*. 1994). Although *Nothofagidites* spp. are abundant in some of the Mulga Rocks samples, high percentages of *Myrtaceidites* spp. in some samples, and a common and highly diverse proteaceous component, indicate a more sclerophyllous woodland character to the vegetation in the depositional area than that reported for coeval southeastern Australian basins.

Palaeobotanical reports from southern WA sediments of the same age provide further insights into the vegetation communities present at that time. Paull & Hill (2010) identified three dissimilar Myrtaceae species and two Proteaceae species from leaf and cuticle specimens, in association with Lauraceae Juss. and Causuarinaceae (*Gymnostoma*) species, in a mudstone collected from the Mulga Rocks site. A further Proteaceae and one Myrtaceae species were identified in a lignite sample along with the same Lauraceae and *Gymnostoma* species recovered from the mudstone sample. The middle Eocene to Oligocene macrofossil flora of West Dale contains a similar predominance of Myrtaceae species to that recognized in the palynoflora at Mulga Rocks and, to a lesser extent, Proteaceae, preserved as leaf fossils (Hill & Merrifield 1993). Sclerophyllous elements observed for both families at West Dale include thick leaves and a lack of obvious rainforest characteristics such as drip tips. Proteaceous leaves are well represented within the late Eocene Kojonup Sandstone flora, with particularly abundant *Banksia*-like leaves (McLoughlin & Hill 1996, McLoughlin & McNamara 2001). A new *Banksia* species with evidence of xeromorphic features has recently been described from this flora (Carpenter *et al*. 2014) implying habitats drier than typical rainforests. Carpenter & Pole (1995) also recognized a high diversity of Proteaceae together with several Banksieae and a few Myrtaceae specimens among 42 cuticle samples studied from late Eocene sediments in the Cowan and Lefroy palaeodrainages. McLoughlin & Guppy (1993) reported leaf impressions from various Paleogene siliceous sandstones in southwestern WA that may include forms representative of the sclerophyllous Proteaceae genera *Petrophile* and *Isopogon* R. Br. ex Knight. Pollen evidence for this kind of community in the late Eocene is seen only in central Australia, where sediments of similar age yielded proteaceous pollen observed by Martin (1982) to have a significant sclerophyllous component. The abundance of proteaceous forms in both the macrofossil and palynofloral assemblages of southern WA and the presence of morphological characters indicative of sclerophylly and/or xeromorphy suggest a prominent sclerophyllous element in the WA Eocene.

Conclusion

The Cenozoic infill in palaeovalleys incised into rocks of the Officer Basin has been relatively unstudied by palynological methods. The analysis of palynofloras from just a few samples of lignitic and carbonaceous material from Mulga Rocks is already providing significant information for dating the sediments, understanding the regional vegetation communities present in the late Eocene, and resolving the early origins of xeromorphy and sclerophylly in Australia. The diverse presence of Myrtaceae and Proteaceae in southern WA macrofossil and palynomorph assemblages, and the discovery of a Myrtaceae-dominated palynoflora at Mulga Rocks, suggests that the southwestern Australian palaeovegetation in the Eocene contained a significant sclerophyllous component and that more of the late Eocene vegetation of WA may have been woodland, dry forest and/or heathland than previously recognized.

Acknowledgements

We acknowledge, first, Associate Professor Kate Trinajstic, for reading early versions of the manuscripts and her support as Charlotte's PhD co-supervisor. Also acknowledged is EMA for providing material for study

including samples, cross-sections and maps of the study area, fieldwork and funding the project. Associate Professor Ron Watkins and our colleagues at EIGG are also thanked, for access to facilities for processing and analysing samples. We thank the editor of *Alcheringa*, and our reviewers for their improvements upon earlier versions of this paper. We would also like to acknowledge Dr Milo Barham, who assisted us in proofreading the manuscript.

References

Al-Shawareb, A., 2009. *Eocene palynology of a lignite section in the Muir-Unicup Catchment, Werillup Formation, south Western Australia*. BSc Honours thesis, University of Western Australia, Perth, 98 pp. (unpublished)

Balme, B.E. & Churchill, D.M., 1959. Tertiary sediments at Coolgardie, Western Australia. *Journal of the Royal Society of Western Australia 42*, 37–43.

Beadle, N.C., 1981. *The Vegetation of Australia*. Gustav Fischer Verlag, Stuttgart, New York, 690 pp.

Bint, A.N., 1981. An early Pliocene pollen assemblage from Lake Tay, south-western Australia, and its phytogeographic implications. *Australian Journal of Botany 29*, 277–291.

Carpenter, R.J. & Pole, M., 1995. Eocene plant fossils from the Lefroy and Cowan paleodrainages, Western Australia. *Australian Systematic Botany 8*, 1107–1154.

Carpenter, R.J., McLoughlin, S., Hill, R.S., McNamara, K.J. & Jordan, G.J., 2014. Early evidence of xeromorphy in angiosperms: stomatal encryption in a new Eocene species of *Banksia* (Proteaceae) from Western Australia. *American Journal of Botany 101*, 1486–1497.

Cookson, I.C., 1950. Fossil pollen grains of proteaceous type from Tertiary deposits in Australia. *Australian Journal of Science, series B 3*, 166–177.

Cookson, I.C., 1959. Fossil pollen grains of *Nothofagus* from Australia. *Proceedings of the Royal Society of Victoria 71*, 25–30.

Cookson, I.C. & Pike, K.M., 1953. The Tertiary occurrence and distribution of *Podocarpus* (section *Dacrycarpus*) in Australia and Tasmania. *Australian Journal of Botany 1*, 71–82.

Cookson, I.C. & Pike, K.M., 1954. Some dicotyledonous pollen types from Cainozoic deposits in the Australian region. *Australian Journal of Botany 2*, 197–219.

Couper, R.A., 1953. Upper Mesozoic and Cainozoic spores and pollen grains from New Zealand. *New Zealand Geological Survey Palaeontological Bulletin 22*, 1–77.

Dawson, J., 1988. *Forest Vines to Snow Tussock: the Story of New Zealand's Plants*. Victoria University Press, Wellington, New Zealand, 264 pp.

De Broekert, P. & Sandiford, M., 2005. Buried inset-valleys in the Yilgarn Craton, Western Australia: geomorphology, age and allogenic control. *The Journal of Geology 113*, 471–493.

Dettmann, M.E., 1963. Upper Mesozoic microfloras from south-eastern Australia. *Proceedings of the Royal Society of Victoria 77*, 1–148.

Dettmann, M.E., Pocknall, D.T., Romero, E.J. & Zamaloa M. del C., 1990. *Nothofagidites* Erdtman ex Potonie 1960: a catalogue of species with notes on the palaeogeographic distribution of *Nothofagus* Bl. (southern beech). *New Zealand Geological Survey Palaeontological Bulletin 60*, 1–79.

Dodson, J.R. & Macphail, M.K., 2004. Palynological evidence for aridity events and vegetation change during the Middle Pliocene, a warm period in Southwestern Australia. *Global and Planetary Change 41*, 285–307.

Douglas, G.B., Butt, C.R.M. & Gray, D.J., 2003. Mulga Rock Uranium and multi-element deposits, Officer Basin, Western Australia. In *Regolith Exploration of Australian Ore Systems*. Butt, C.R.M., Robertson, I.D.M., Scott, K.M. & Cornelius, M., eds, CRCLEME, Canberra, 415–417.

Fewster, M., 1999. *The Geology of the Narnoo Basin, Western Australia, and Origin of the Gold, Base-Metal, and Uranium Mineralisation During the Late Cenozoic*. MSc thesis, University of Western Australia, Perth, 138 pp. (unpublished)

Floyd, A.G., 1989. *Rainforest Trees of Mainland South-eastern Australia*. Inkata Press, Melbourne, 420 pp.

Foreman, D.B., 1995. *Xylomelum* (Proteaceae). *Flora of Australia, Vol. 16*. CSIRO Publishing, Melbourne, 399–403.

Harris, W.K., 1965. Basal Tertiary microfloras from the Princetown area, Victoria, Australia. *Palaeontographica B 115*, 75–106.

Harris, W.K., 1972. New form species of pollen from southern Australian Early Tertiary sediments. *Transactions of the Royal Society of South Australia 96*, 53–65.

Hekel, H., 1972. Pollen and spore assemblages from Queensland Tertiary sediments. *Geological Survey of Queensland Publication 355*, 1–34.

Hill, R.S., 1990. Evolution of the modern high latitude Southern Hemisphere flora: evidence from the Australian macrofossil record. In *Proceedings of the 3rd International Organisation of Palaeobotany Conference*. Douglas, J.G. & Christophel, D.C., eds, A-Z Printers, Melbourne, 31–42.

Hill, R.S. & Merrifield, H.E., 1993. An Early Tertiary macroflora from West Dale, Southwestern Australia. *Alcheringa 17*, 285–326.

Hos, D., 1975. Preliminary investigations of the palynology of the upper Eocene Werillup Formation, Western Australia. *Journal of the Royal Society of Western Australia 58*, 1–14.

Islam, M.A., 1983. Palynological report on samples from the western Eucla Basin. *Report R12/83/1*. ECL Australia Pty Ltd, 7 pp. (unpublished)

Johnson, L.A.S., 1982. Notes on the Casuarinaceae II. *Journal of the Adelaide Botanical Gardens 6*, 73–87.

Macphail, M.K., 1999. Palynostratigraphy of the Murray Basin, inland southeastern Australia. *Palynology 23*, 197–240.

Macphail, M.K., 2007. Australian palaeoclimates: Cretaceous to Tertiary—A review of palaeobotanical and related evidence to the year 2000. *CRC LEME Special Volume Open File Report 151*, 1–266.

Macphail, M.K., Alley, N.F., Truswell, E.M. & Sluiter, I.R.K., 1994. Early Tertiary vegetation: evidence from spores and pollen. In *History of the Australian Vegetation: Cretaceous to Recent*. Hill, R.S., ed., Cambridge University Press, Cambridge, 189–261.

Martin, H.A., 1973. Upper Tertiary palynology in southern New South Wales. *Special Publications of the Geological Society of Australia 4*, 35–54.

Martin, H.A., 1974. The identification of some Tertiary pollen belonging to the family Euphorbiaceae. *Australian Journal of Botany 22*, 271–291.

Martin, H.A., 1978. Evolution of the Australian flora and vegetation through the Tertiary: evidence from pollen. *Alcheringa 2*, 181–202.

Martin, H.A., 1982. Changing Cenozoic barriers and the Australian paleobotanical record. *Annals of the Missouri Botanical Garden 69*, 625–627.

Martin, H.A., 1992. The Tertiary of southeastern Australia: was it tropical? *Palaeobotanist 39*, 270–280.

McIntyre, D.J., 1968. Further new pollen species from New Zealand Tertiary and uppermost Cretaceous deposits. *New Zealand Journal of Botany 6*, 177–204.

McLoughlin, S. & Guppy, L., 1993. Western Australia's Tertiary floras. *The Fossil Collector 40*, 13–22.

McLoughlin, S. & Hill, R.S., 1996. The succession of Western Australian Phanerozoic floras. In *Gondwanan Heritage: Past, Present and Future of the Western Australian Biota* (Proceedings of the Conference on Systematics, Evolution and Conservation of the Western Australian Biota, Perth, 1993). Hopper, S.D., Chappill, J.A., Harvey, M.S. & George, A.S., eds, Surrey Beatty, Sydney, 61–80.

McLoughlin, S. & McNamara, K., 2001. *Ancient Floras of Western Australia*. Western Australian Museum, Perth, 42 pp.

Mildenhall, D.C. & Harris, W.F., 1971. Status of *Haloragacidites* (al. *Triorites*) *harrisii* (Couper) Harris comb. nov. and *Haloragacidites trioratus* Couper, 1953. *New Zealand Journal of Botany 9*, 297–306.

MILDENHALL, D.C. & POCKNALL, D.T., 1989. Miocene-Pleistocene spores and pollen from Central Otago, South Island, New Zealand. *New Zealand Geological Survey Paleontological Bulletin 59*, 1–128.

MILNE, L.A., 1988. Palynology of a late Eocene lignitic sequence from the western margin of the Eucla Basin, Western Australia. *Memoirs of the Association of Australasian Palaeontologists 5*, 285–310.

MILNE, L.A., 1994. Relationship between *Propylipollis annularis* (Tertiary dispersed pollen) and extant *Xylomelum* (Proteaceae). In *Ultrastructure of Fossil Spores and Pollen*. KURMANN, M.H. & DOYLE, J.A., eds, Royal Botanic Gardens, Kew, 193–213.

MILNE, L.A., 1997. *Palynology of Selected Extant Proteaceae and Eocene Palynofloras of Western Australia*. PhD thesis, The University of Queensland, Queensland, 191 pp. (unpublished)

MILNE, L.A., 1998. Tertiary palynology: *Beaupreadites* and new Conospermeae (Proteoideae) affiliates. *Australian Systematic Botany 11*, 553–603.

PAIJMANS, K., 1976. *New Guinea Vegetation*. Australian National University Press, Canberra, 212 pp.

PARTRIDGE, A.D., 1976. The geological expression of eustacy in the early Tertiary of the Gippsland Basin. *APEA Journal 16*, 73–79.

PARTRIDGE, A.D., 2006. Late Cretaceous–Cenozoic palynology zonations Gippsland Basin. In *Australian Mesozoic and Cenozoic Palynology Zonations*. MONTEIL, E., coord., Geoscience Australia Record 2006/23.

PAULL, R. & HILL, R.S., 2010. *Report on Leaf Fossils Removed from Drill-Hole NND5004, Mulga Rocks Uranium Deposit, Western Australia*. Report, University of Adelaide, Adelaide, 21 pp. (unpublished)

PHIPPS, D. & PLAYFORD, G., 1984. Laboratory techniques for extraction of palynomorphs from sediments. *Papers of the Department of Geology, The University of Queensland 11*(1), 1–23.

POCKNALL, D.T. & CROSBIE, Y.M., 1982. Taxonomic revision of some Tertiary tricolporate and tricolpate pollen grains from New Zealand. *New Zealand Journal of Botany 20*, 7–15.

POCKNALL, D.T. & MILDENHALL, D.C., 1984. Late Oligocene–early Miocene spores and pollen from Southland, New Zealand. *New Zealand Geological Survey Paleontological Bulletin 51*, 1–66.

POWIS, G.D., 1979. Palynological Reports. *Palynological Report 359*. Palaeoservices Australia, 16 pp. (unpublished)

PRIDER, J.N. & CHRISTOPHEL, D.C., 2000. Distributional ecology of *Gymnostoma australianum* (Casuarinaceae), a putative palaeoendemic of Australian wet tropic forests. *Australian Journal of Botany 48*, 427–434.

READ, J., HOPE, G.S. & HILL, R.S., 1990. Integrating historical and ecophysiological studies in *Nothofagus* to examine the factors shaping the development of cool rainforest in southeastern Australia. In *Proceedings of the 3rd International Organisation of Palaeobotany Conference*. DOUGLAS, J.G. & CHRISTOPHEL, D.C., eds, A-Z Printers, Melbourne, 97–106.

SCRIVEN, L.J. & HILL, R.S., 1995. Macrofossil Casuarinaceae: their identification and the oldest macrofossil record, *Gymnostoma antiquum* sp. nov., from the late Paleocene of New South Wales. Australia. *Australian Systematic Botany 8*, 1035–1053.

SCRIVEN, L.J., MCLOUGHLIN, S. & HILL, R.S., 1995. *Nothofagus plicata* (Nothofagaceae), a new deciduous Eocene macrofossil species, from southern continental Australia. *Review of Palaeobotany and Palynology 86*, 199–209.

STOVER, L.E. & EVANS, P.R., 1973. Upper Cretaceous–Eocene spore-pollen zonation, offshore Gippsland Basin, Australia. *Geological Society of Australia, Special Publication 4*, 55–72.

STOVER, L.E. & PARTRIDGE, A.D., 1973. Tertiary and Late Cretaceous spores and pollen from the Gippsland Basin, southeastern Australia. *Proceedings of the Royal Society of Victoria 85*, 237–286.

STOVER, L.E. & PARTRIDGE, A.D., 1982. Eocene spore-pollen from the Werillup Formation, Western Australia. *Palynology 6*, 69–95.

THORNHILL, A.H. & MACPHAIL, M., 2012. Fossil myrtaceous pollen as evidence for the evolutionary history of Myrtaceae: A review of fossil *Myrtaceidites* species. *Review of Palaeobotany and Palynology 176–177*, 1–23.

TRUSWELL, E.M., 1983. Recycled Cretaceous and Tertiary pollen and spores in Antarctic marine sediments: a catalogue. *Palaeontographica B 186*, 121–174.

TRUSWELL, E.M., 1993. Vegetation changes in the Australian Tertiary in response to climatic and phytogeographic forcing factors. *Australian Systematic Botany 6*, 533–557.

TRUSWELL, E.M. & OWEN, J.A., 1988. Eocene pollen from Bungonia, New South Wales. *Association of Australasian Paleontologists Memoir 5*, 259–284.

WATERHOUSE, J.D., COMMANDER, D.P., PRANGLEY, C. & BACKHOUSE, J., 1994. Newly recognized Eocene sediments in the Beaufort River Palaeochannel. *GSWA 1993–94 Review*, 82–86.

WILSON, L.R. & WEBSTER, R.M., 1946. Plant microfossils from a Fort Union coal of Montana. *American Journal of Botany 33*, 271–278.

WRIGLEY, J.W. & FAGG, M., 1989. *Banksias, Waratahs and Grevilleas, and all Plants in the Australian Proteaceae family*. Harper and Collins, London, 584 pp.

Species	Figure	Slide number	England finder coordinates	Registration number
Ailanthipites paenestriatus	1O	7/1	V48/4	F52244
Anacolosidites sectus	1A4, A5	5B/2	V27/4	F52245
Banksieaeidites sp. 1	2B	5/2	P50/4	F52246
Banksieaeidites sp. 2	2C,D	5/2	P50/0	F52247
Dacrycarpidites australiensis	1C	6A/1	L25/1	F52248
Gleicheniidites circinidites	1B	7B/2	W50/3	F52249
Haloragacidites harrisii	2A	1H/1	N27/3	F52250
Laevigatosporites ovatus	1A	7B/2	Q52/0	F52251
Liliacidites aviemorensis	1G	4F/1	S65/4	F52252
Lygistepollenites florinii	1D	2/1	S31/0	F52253
Malvacipollis diversus	2U	2/1	F38/1	F52254
Myrtaceidites eucalyptoides	1S	2H/2	T49/0	F52255
Myrtaceidites eucalyptoides	1T	7/1	O40/1	F52256
Myrtaceidites mesonesus	1U	2H/2	S46/0	F52257
Myrtaceidites sp.	1P	7B/2	W32/0	F52258
Myrtaceidites sp.	1Q,R	2/1	T24/4	F52259
Nothofagidites brachyspinulosis/incrassatus	1V,W	4/3	Q46/1	F52260
Nothofagidites emarcidus/heterus	1Y	2F/1	K43/2	F52261
Nothofagidites emarcidus/heterus	1X	2F/1	L39/4	F52262
Nothofagidites falcatus	1Z	5/2	Q58/0	F52263
Nothofagidites spinosus	1A1	3/2	J52/1	F52264
Proteacidites annularis	2I	4C/2	Q34/1	F52265
Proteacidites bremerensis	2O	3/2	T48/1	F52266
Proteacidites carobelindiae	2J,K	2H/1	U49/4	F52267
Proteacidites cirritulis	2F	3F/1	L23/1	F52268
Proteacidites crassus	2N	5B/2	Q59/4	F52269
Proteacidites confragosus	2S	3F/1	P34/3	F52270
Proteacidites cumulus	2T	8A/1	M51/2	F52271
Proteacidites nasus	2P,Q,R	2/1	M49/2	F52272
Proteacidites obscurus	2G,H	4H/2	U51/0	F52273
Proteacidites pachypolus	2E	4F/1	O27/1	F52274
Proteacidites reticulatus	2L,M	2F/2	C38/1	F52275
Rhoipites alveolatus	1I	1H/2	G27/0	F52276
Rhoipites angurium	1L,M	8/2	L44/0	F52277
Rhoipites goulburnensis	1N	8A/1	K31/2	F52278
Santalumidites cainozoicus	1A2,A3	4C/2	Y37/0	F52279
Tricolpites incisus	1A6,A7	5A/1	E50/2	F52280
Tricolporites adelaidensis	1F	3D/1	M44/0	F52281
Tricolporites leuros	1H	1A/1	V33/0	F52282
Tricolporites scabratus	1J,K	6A/1	V50/3	F52283

Appendix A. Register of illustrated specimens.

DRILL PROGRAM	CD																			OF	NNA	
Well	481				763				1			1485		1360	779	409				52	5025	5510	
Depth (m)	39	41	42.2	43.3	45.3	55	65	72.9	35.1	40	67	39	40.7	41	81	31.1	34.8	41	45	86	73	75	79
Lithological Interval	E	E	E	E	E	E	E	D	E	E	D	E	E	E	E	E	E	E	E	E	E	D	D
Cryptogam spores																							
Baculatisporites comaumensis		0.5		+	0.5			+	+		0.5	+			1		0.5			1	+		
Cyathidites australis			+								+				+								
C. minor		+									0.5												
C. spp.																+							
Gleicheniidites circinidites		+		+				0.5												+	0.5		
Laevigatosporites ovatus	+			0.5				1	1		+			+	0.5	+			0.5	+	1	0.5	
Retriletes austroclavatidites		+																					
Verrucatosporites speciosus		+		+	+			+												1	+	+	
Verrucosisporites kopukuensis		+		+	+			0.5			+									+			
Gen. et sp. indet.	0.5	1.5	0.5	0.5	1			0.5	+	0.5	1.5			+	+	+	1.5		5.5	1.5	0.5		
Gymnosperms																							
Dacrycarpidites australiensis					0.5																	0.5	
Lygistepollenites florinii	+	5	+	3	4	2		+	1	1	2	+	3.5		1	+	1	0.5	+	+	2	0.5	+
Microcachrydites brevisaccatus		+	+										0.5							+			
Phyllocladidites mawsonii		2.5		1.5	0.5	0.5	0.5			0.5	+			3		0.5		0.5		+	+	2.5	
Podocarpidites ellipticus	+	2		2	1.5	0.5	1	0.5	1		2	0.5	1	0.5	1	1			1.5	3	0.5	0.5	+
P. puteus		2							+														
P. spp.									+							+							
Trichotomosulcites subgranulatus										+												0.5	
Angiosperms																							
Aglaoreidia qualumis														+									
Ailanthipites paenestriatus					0.5		2	+	0.5		0.5	1		+			+				0.5	1	1.5
Anacolosidites acullutus			+					+			+									+			
A. luteoides														2.5									
A. sectus																				+			+
Banksieidites arcuatus	2	0.5	1	1	+	+		2	0.5	2	2	+		8.5		0.5	4.5	0.5	+	3	+	2	2.5
B. sp. 1	+	+	+			1.5				+	+	+			+			+	+		+		
B. sp. 2		+	+	+	+	2				+		+			+							+	
Beaupreaidites diversiformis		+	+		+																		
B. elegansiformis																				+			
B. verrucosus	+		+		0.5			+			+	+	+				+			+		+	+
Clavatipollenites glarius			1	0.5						+						5.5							
Cupanieidites sp. cf. *C. major*						+			+														
C. orthoteichus	0.5	+	+	0.5			0.5		+		0.5	+		1	1			+		+	1.5	+	+
C. reticularis		0.5	+	+	0.5	0.5		0.5	0.5				+		0.5			+		+	+	1	1
C. spp.																				0.5			
Ericipites scabratus	+		+	0.5	+		2	1	6		2.5	+		0.5			0.5	0.5		0.5	1	1.5	0.5
Gothanipollis bassensis	+			+				0.5			+			2			0.5						+

(*Continued*)

Appendix B (*Continued*).

DRILL PROGRAM	CD																			OF	NNA	
Well	481				763				1			1485		1360	779	409				52	5025	5510	
Depth (m)	39	41	42.2	43.3	45.3	55	65	72.9	35.1	40	67	39	40.7	41	81	31.1	34.8	41	45	86	73	75	79
Lithological Interval	E	E	E	E	E	E	E	D	E	E	D	E	E	E	E	E	E	E	E	E	E	D	D
Haloragacidites harrisii	32.5	13	20.5	9	15	15.5	19	5	23.5	7.5	11	19	41.5	8.5	5.5	53.5	31	35.5	30	4	2	1.5	7.5
H. sp. cf. *H. harrisii*						+							1.5		+		+			+			+
Ilexpollenites anguloclavatus	+		+					0.5				+								+	+	1	+
Liliacidites aviemorensis			0.5					1	5		0.5			2		+				+		+	+
L. bainii	+								+														
Malvacipollis diversus	6.5	3.5	6	0.5		1	1.5		11.5		0.5	+	17	0.5	1	22.5	12.5	17.5	37.5	+	+	0.5	0.5
M. subtilis				+	3.5		0.5			+											+		
Myrtaceidites eucalyptoides		1		2				+	0.5	0.5				4.5							+		1
M. mesonesus	2.5	16	0.5	18	33.5	8.5	2.5	34.5	2.5	11.5	25	12	5.5	41	32		22.5	7	2	22	50	13	20
M. spp.	+	1.5		+	+			+			+			4.5	1				+	+	4.5		
Nothofagidites falcatus	3.5	9.5	3	6.5	4.5	2		1	1.5	3	2.5	8	3		0.5	4	3.5	0.5	0.5	0.5	+	1.5	2.5
N. heterus/emarcidus	19.5	10	14	16.5	6.5	23	17.5	27	16	21.5	14.5	22.5	9.5	1	26	4	5.5	8.5	16	31	9.5	23.5	26.5
N. incrassatus/brachyspinulosis	23	17.5	44	28	15	32.5	13.5	11.5	14	29	9	18.5	7	0.5	8	4	3.5	21	4	13	8.5	18.5	13.5
N. senectus	+				0.5							+										+	+
N. spinosus			+	+					+														
N. vansteenisii				+	+			+			+	3.5			3			0.5				+	
Periporopollenites demarcatus	0.5	1.5	+	2		+	4.5		2	+		+	+	1	1	1.5	+	+		0.5	1	+	1
Polycolporopollenites esobalteus								+			1	+		1				+				+	+
Propylipollis biporous								0.5							+					0.5			
P. sp. cf. *P. robustus*				+				+		0.5	3.5				+					+		+	+
Proteacidites adenanthoides	+			+				0.5		+		+			0.5		+	+		1.5	0.5		+
P. annularis	+		1	+	0.5	3		1.5		3	0.5	+	1		1.5		0.5	+	0.5	1	0.5	1.5	2.5
P. bremerensis				+					+														
P. carobelindiae	+		+								0.5	+		0.5									+
P. cirritulis	0.5	1	2.5	0.5	1.5	0.5	1.5	+	0.5	3.5	+	4.5	0.5	0.5	1.5		0.5			+	1	0.5	2
P. confragosus	+		+		+				+		0.5							+			+		
P. crassus	+		+	+	+		18	0.5	+	0.5	+	1	2					+	+	1	0.5	+	0.5
P. cumulus		+	+						+		0.5				+					+			
P. ivanhoensis	0.5	0.5		0.5	0.5	+					1	0.5								2		0.5	
P. leightonii	+	0.5							+				0.5					+				+	
P. microverrucatus																						+	
P. nasus	+	+	+								+	+						+					
P. sp. cf. *P. nasus*									+		+						+		+	0.5		1	
P. 'notredamus'	+	+	+																				
P. sp. cf. *P. 'notredamus'*			+	+													+			+			
P. obscurus	+	+		0.5	+		0.5	0.5	+				+				3.5	0.5		+		0.5	1
P. pachypolus	0.5		+	0.5	+		4.5	1.5	5	+	+		+		0.5			+	0.5	1.5	1	2	2.5
P. pseudomoides				0.5						0.5	0.5		0.5				+			+	0.5		2
P. sp. cf. *P. pseudomoides*								1.5		0.5					1			+			0.5	4	

P. reticulatus	+	+	+		0.5			+		+		+						+					
P. rynthius				+				0.5							+								
P. sp. cf. *P. rynthius*	+		0.5		1											+	1	+					
P. scitus	+										+							+					
P. tenuiexinus										0.5													0.5
P. spp.	1	+	2.5	1	0.5			+	1	1	+	1	1.5		2	+	4	4.5	+	2	1.5	3	1.5
Rhoipites alveolatus															+								+
R. angurium	+	0.5	+		1		0.5	+	+	4.5	0.5		+	1.5	1	1	1	1.5	0.5	1	+	3	+
R. goulburnensis	+	+													+		0.5	+	+		+	1.5	0.5
R. ivanhoensis	+	2	+	+	+			+			0.5	1			1					+	0.5		+
R. microreticulatus		1.5	+		1			0.5			0.5			1.5	1					+	1		3
R. minutiformis	2.5			1.5	1.5	1		1		1.5		1.5		2.5		0.5				0.5	3	8	1.5
R. spp.	+	+	0.5		+			+	+	+	1.5	0.5		+	0.5					+	1	0.5	0.5
Santalumidites cainozoicus		+	+			+		+	+		0.5	+	+		1			+		+	+		0.5
Sapotaceoidaepollenites rotundus	1.5				+	+				1	1	+	0.5		1.5	+	+	+			0.5	+	+
Schizocolpus marlinensis											0.5				+							0.5	+
Sparganiaceaepollenites barungensis									+	+										+			
S. spp.																							0.5
Tetracolporites palynius	+	0.5			+	2.5				+										+			
Tricolpites incisus		+	+		+	+		+	+		+				1					0.5	0.5	+	+
T. spp.	0.5	+	+					1	0.5			0.5	0.5					+		+	+	0.5	
Tricolporites adelaidensis			+									+											
T. sp. cf. *T. coprosmoides*		0.5																					
T. sp. aff. *T. pelargonium*		+																					
T. leuros		0.5	0.5	+		+			0.5	1		0.5			0.5					2	+	0.5	+
T. prolata			0.5	0.5			1							1.5	+						2.5		1
T. scabratus	+								2					1							+		
T. sphaerica		0.5	+					0.5		+	0.5	+		2							+	1	1
T. spp.	0.5	+	+	0.5				+		+	1	0.5	0.5	1	0.5	+	0.5	0.5	1	+	0.5	+	+
Triorites scabratus			+						+			+											
Triporopollenits ambiguus			+																				
T. apiculatus															+								
T. sp. cf. *T. delicatus*																	+			0.5			
T. gemmatus								0.5		0.5					0.5	+				+			
Gen. et sp. indet.	1.5	4	1	1.5	4	3.5	9	2	3.5	4.5	10.5	3.5	2.5	5.5	1.5	1.5	1.5	0.5	0	4	1.5	1.5	1

Appendix B. Distribution of fossil pollen species in Mulga Rocks drill core: CD data derived from PNC core and OF and NNA from EMA drilling programs.

9. New *Banksieaeidites* species and pollen morphology in *Banksia* L.f.

9.1 Preface to chapter

This chapter has been submitted to the journal of Australian Systematic Botany and has been accepted with minor revisions. Appendices and photographic plates which are associated with the paper are contained in Appendix 10 of this thesis.

This manuscript describes the pollen morphology of eight species of extant *Banksia* selected from its two subgenera, in order to establish the characters that define the pollen produced by the genus. Two new species of *Banksieaeidites*, *B. cooksonii* and *B. davidsonii*, are described and compared against the morphology of the extant *Banksia* pollen. The comparison of characters between *Banksia* subgenera (*B.* subgen. *Banksia* and *B.* subgen. *Spathulatae*), and the changes in morphology of *Banksia* pollen grains as they mature, is also discussed.

In this thesis, the conclusions of the paper add to the discussion of the palaeovegetation at Mulga Rock during the late Eocene. *Banksia* L.f. is a prominent component of modern Australian sclerophyll flora. The presence of fossil pollen species with characters that are distinctly *Banksia* allows for a distinction to be made between them and the fossil pollen species *Banksieaeidites arcuatus*. *B. arcuatus* resembles pollen produced by the other Banksieae subtribe, Musgraveinae, which consists of two rainforest genera (*Musgravea* and *Austromuellera*). As both new species described share characters that are distinctly *Banksia* and are prominent in the Mulga Rock palynoflora, it suggests that the palaeovegetation included a distinct scleromorphic component.

9.2 Abstract

Cookson (1950) erected the fossil pollen genus *Banksieaeidites* to accommodate palynomorphs with characters resembling those of the extant Proteaceae genus *Banksia*. One of the most commonly reported species, *Banksieaeidites arcuatus*

Stover and Partridge 1973, is now known to more closely resemble pollen of the Proteaceae subtribe Musgraveinae.

The Late Eocene Mulga Rocks deposits in the southern Officer Basin of Western Australia have yielded palynofloras that contain up to 7% of two new species that can confidently be aligned with pollen of modern *Banksia*. *Banksieaeidites cooksonii* sp. nov. and *B. davidsonii* sp. nov. are formally described, and pollen from eight extant *Banksia*; *Banksia ashbyi* Baker f., *B. attenuata* R. Br., *B. baxteri* R. Br., *B. burdettii* Baker f., *B. grandis* Willd., *B. menziesii* R. Br., *B. occidentalis* R. Br. and *B. tricuspis* Meisn. are described and compared with the fossil species. The variation in extant *Banksia* pollen morphology, and that between the two *Banksia* subgenera (*B.* subgen. *Banksia* and *B.* subgen. *Spathulatae*) are discussed, and the changes in the morphology of *Banksia* pollen grains as they mature is reported.

9.3 Introduction

Banksia L.f. (Proteaceae tribe Banksieae) is a common and often dominant component of modern Australian sclerophyllous vegetation communities such as heath and low woodland (George 1999). Tribe Banksieae is comprised of two subtribes, Musgraveinae that contains the genera *Musgravea* and *Austromuellera*, and the larger Banksiinae that includes *Banksia* and what was previously assigned to *Dryandra*. The inclusion of *Dryandra* within Banksiinae on the basis of DNA evidence (Mast and Thiele 2007, Thiele and Mast 2007) brings the total number of species included within *Banksia* to over 170. The recent phylogeny of Cardillo and Pratt (2013) supports the further division of *Banksia* into two subgenera, *B.* subgenus *Banksia* and *B.* subgenus *Spathulatae*, by Mast and Thiele (2007).
Banksia is primarily endemic to Australia, with the exception of *B. dentata* which grows in New Guinea, the Aru Islands and northern Australia. The majority of extant *Banksia* occur in southwestern Western Australia and eastern Australia. The Southwest Australian Floristic Region (SWAFR) of Hopper and Gioia (2004) is the present centre of diversity for *Banksia*, with more than 90% of species growing in the area. *Banksia* ranges from prostrate shrubs to trees reaching a height of 1.5 m to 10 m (George 1999), though the tallest recorded reached 30 m (Collins *et al.* 2008). The

highest density of species grow within scrub-heath and low woodland and are generally restricted to oligotrophic soils over a broad range of climates, though most occur where the annual rainfall is between 500 mm and 1000 mm (Greenwood *et al.* 2001). Many species grow in sand of varying depths in exposed coastal areas, sand dunes and sand plains; some occur in laterite, a few are restricted to rocky substrates and several species prefer swampy conditions (Wrigley and Fagg 1989). Eastern Australia has significantly fewer species than Western Australia, with only 16 occurring from north Queensland through to Tasmania (Collins *et al.* 2008). Published studies of *Banksia* pollen are limited, with the most detailed treatment by Sedgley *et al.* (1993) only considering broad measurements of grains and general shape. Cookson (1950) and Johnson and Briggs (1975) noted a few additional characteristics. The pollen of modern species herein described not only allow the establishment of characters that are distinctly *Banksia* for comparative fossil work and palaeovegetation analyses, but also provide a resource for ongoing forensic cases and environmental studies that may require the identification of these species.

Fossil evidence of *Banksia* include banksioid leaves, wood, pollen and fruiting cones that range from Palaeocene to Pleistocene in age, and are found at sites corresponding to much of the modern distribution of *Banksia* (Redaway 1858, Smyth 1873, 1875 Cookson 1950, Cookson and Duigan 1950, Pike 1953, Patton 1958, Blackburn 1981, Hill and Macphail 1983, McNamara and Scott 1983, Hill 1988, Hill and Christophel 1988, Jordan and Hill 1991, McNamara 1992, Hill and Merrifield 1993, Carpenter *et al*. 1994, Vadala and Drinnan 1998, Greenwood *et al.* 2001, Carpenter *et al.* 2014). Cookson (1950), in erecting *Banksieaeidites* Cookson for fossil pollen closely resembling pollen of living *Banksia,* formally described *Banksieaeidites elongatus* and *B. minimus*. Stover and Partridge (1973) described a third, *B. arcuatus,* but the discovery of an inflorescence containing pollen of similar morphology has since shown that *B. arcuatus* more closely resembles pollen of the Musgraveinae (Christophel 1984).

Stover and Partridge (1973) subsumed the two species described by Cookson (1950) into one species, *B. elongatus*, reporting that the Gippsland Basin sediments contained specimens with intermediate characters. Cookson (1950) differentiated *B. minimus* and *B. elongatus* on numerous characters including size and sculpture, but

Stover and Partridge (1973) only refer to size in the emendment of the species; giving a size range of 21 to 45 µm in length, 18 to 28 µm in width and an aperture diameter of 9 to 18 µm. These are unusually large size ranges for one species. Considering the differing morphology of *B. minimus* and *B. elongatus* as described by Cookson (1950), and the presence of the intermediates reported by Stover and Partridge (1973), *B. elongatus* as currently described likely contains a number of morphotypes and fossil species. The lumping of a range of morphotypes into one fossil species is expedient for biostratigraphic purposes where they are not index species, but this is not satisfactory for evaluating the palaeovegetation and diversity of a taxon within it.

The fossil leaf record is well distributed and extensive in southern Australia, with many leaves recognisable as *Banksia sensu stricto* due to clear similarities in gross morphology (Cookson and Duigan 1950, Hill and Christophel 1988, Carpenter *et al.* 1994, McLoughlin and Hill 1996, Greenwood *et al.* 2001, Carpenter *et al.* 2014). Cookson and Duigan (1950) made the initial assignment of leaf fossils resembling *Banksia* to *Banksieaephyllum*. More recent studies just assign fossil leaves to *Banksia*. To date, the oldest reported *Banksia* macrofossil is known from late Palaeocene-aged rocks in eastern Australia (Lake Bungarby in New South Wales) and shows evidence of sclerophylly (Carpenter 1994). Xeromorphic characters are recognised in the late Eocene, with the recent description of a *Banksia* leaf fossil from the Kojonup Sandstone of WA that preserves the current oldest record of stomatal encryption in the genus (Carpenter *et al.* 2014). The Kojonup Sandstone contains at least five *Banksieaephyllum* taxa and the Middle Eocene to Oligocene West Dale macroflora at least three (Hill and Merrifield 1993, McLoughlin and Hill 1996). In addition to possessing morphological features that indicate sclerophylly, and in some cases xeromorphy, *Banksia* leaf fossils also occur in assemblages of other presumably drought-sensitive taxa at multiple fossil sites in Australia (Carpenter and Jordan 1997, Carpenter *et al.* 2011).

Eocene palynofloras from Mulga Rocks in the Gunbarrel Basin of southern Western Australia include two undescribed species of *Banksia*-like palynomorphs (Mack and Milne 2015), here formally described as *Banksieaeidites cooksonii* and *B. davidsonii*. The variation in extant *Banksia* pollen morphology, and that between the two *Banksia* subgenera (*B.* subgen. *Banksia* and *B.* subgen. *Spathulatae*) are discussed,

and the changes in the morphology of *Banksia* pollen grains as they mature is reported. Plates B1 and B2 illustrate the morphology of the fossil pollen species and plates B3 to B7 illustrate the pollen morphology of the modern *Banksia* described (Appendix 10).

9.4 Materials and methods

The fossil species were collected from the Eocene Mulga Rocks deposits (southern Officer Basin, Western Australia), a tenement held by Vimy Resources (formerly Energy and Minerals Australia). Sediment samples were collected from multiple diamond and air core holes drilled between 1979 and 2012. Distribution of fossil species in cores is listed in Appendix 10A.

Processing of sediments was based on the method outlined by Phipps and Playford (1984) which involves acid digestion of minerals and oxidation of extraneous organic matter. A portion of the resulting organic residue was mounted on glass microscope slides in 'Eukitt' for light microscopy. For scanning electron microscopy (SEM), a drop of residue was placed on thermoplastic ('Thermanox') cover slips and mounted on SEM stubs.

Modern pollen was obtained from herbarium sheets (Appendix 10B) held at the Perth Herbarium. The eight species selected to study cover both the subgenera (*Banksia* subgenera *Banksia* and *B.* subgenera *Spathulatae*) and several different clades within each subgenus. Species previously included within *Dryandra* were excluded on the basis of a distinct elongation and curvature to *Dryandra* pollen studied by L. Milne (pers. comm.). For each species, five to eight mature anthers and one to two immature anthers were collected from at least three separate herbarium sheets, and processed following the standard acetolysis technique of Erdtman (1960). Samples were prepared for light microscopy and SEM as for the fossil pollen. Morphological terminology follows that of Punt *et al*. (2007), which amalgamates information from other palynological glossaries, in particular that of Kremp (1965), Moore *et al*. (1991), and Faegri *et al*. (1989). Light microscopy was used for species diagnoses and holotype descriptions with sculptural detail obtained from SEM

observations. For light microscopy, ‘sexine’ and ‘nexine’ were used to differentiate layers of the pollen wall, *sensu* Erdtman (1952). Where observed, the sexinous layers are termed ‘tectum’ and ‘infratectum’. Descriptions of modern pollen are based on measurement of 30 grains, *B. cooksonii* on 35 grains and *B. davidsonii* on the amount of material available (22 grains). The sample size was chosen on the basis of work carried out by Wrońska-Pilarek *et al*. (2015), which determined that a sample size of approximately 30 grains is required to obtain representative mean values as well as variability data, and a sample size of 15 to 20 was sufficient when considering mean values.

Light photomicrographs were taken with an OLYMPUS-P71 digital camera attached to an OLYMPUS-BX51 transmitted light biological microscope. For SEM, specimens were imaged on a Tescan Mira3 FESEM. All illustrated specimens are housed with the Geological Survey of Western Australia. For each figured specimen, Appendix 10C lists the preparation and slide number, England Finder stage coordinates, and repository catalogue number.

9.5 Geological setting and age of sediments

The Mulga Rocks deposits are located approximately 250 km east-northeast of Kalgoorlie in a tectonically defined palaeochannel within the Mesozoic sediments of the Gunbarrel Basin, and overlying the glacigene Paterson Formation, Western Australia (Hocking pers. comm.). The sedimentary succession within this palaeovalley includes Cretaceous through to Quaternary aged units. To date, these units have only been tentatively correlated (Fewster 1999) to established stratigraphic schemes for the Eucla Basin (Clarke 1993, 1994) and similar palaeovalleys on the Yilgarn Craton. An informal alpha-numeric reference system is used by Vimy Resources, the current holders of an exploration tenement over the site. Two units of lignite and carbonaceous clays and sands have yielded a rich palynoflora referable to the Middle *Nothofagidites asperus* Zone (Stover and Partridge 1973; Partridge 1976) and its equivalent in the Murray Basin (Macphail 1999), dated as Late Eocene in age (Mack and Milne 2015).

9.6 Systematic palynology

9.6.1 Fossil material

Genus *Banksieaeidites* Cookson ex Couper 1954

Type species Banksieaeidites elongatus Cookson ex Couper 1954

Banksieaeidites cooksonii sp. nov. (Plate B1, Figs G–V)

Etymology: Named for the inspirational palaeobotanist and palynologist, Dr Isabel Cookson, who erected *Banksieaeidites.*

Diagnosis (*TLM)*: Pollen diporate, anisopolar; amb in equatorial view elliptical with ends truncated, biconvex to slightly plano-convex. Exine 1.25–2.75 µm, thickening to 2–4 µm at apertures, distinctly stratified; nexine thicker than sexine. Exine significantly thinner in mature specimens. Nexine thins significantly at start of apertural collar and thickens towards the aperture through the collar. Sexine thins to the aperture, in some cases completely absent at the aperture margins; microrugulate in most cases, rarely microreticulate. Apertures lalongate, 7–16 µm in diameter, widening with maturity, with ragged margins. Apertural collar present, 3–6 µm deep.

Sculptural detail (SEM): Tectum rugulo-tectate perforate, with lalongate to circular perforations; rugulae straight to curved, 0.7–2.4 µm long, 0.3–0.7 µm wide, width variable over length of rugulae; circular perforations 0.04–0.3 µm in diameter, larger at apertures, 0.17–0.86 µm apart; elongate perforations appear to be formed from sinking of tectum between circular perforations, 0.2–1.03 µm long, occasionally joining three at 120° from each other. Rugulae surface smooth at lower magnifications, slightly wrinkled at higher magnifications.

Dimensions: 26 (30) 35 µm, width 18 (23) 30 µm (35 specimens)

Holotype: (Plate B1, Figs G–I) Pollen diporate, anisopolar; amb in equatorial view elliptical with ends truncated, symmetrically biconvex. Exine 2 µm, thickening to 2.5 µm at the apertures, distinctly stratified; nexine significantly thicker than sexine. Nexine decreases by 0.5 µm prior to the apertural collar in a notch 1 µm wide, before thickening through the apertural collar. Sexine thins to aperture;

microrugulate. Apertures lalongate, 11 µm in diameter, with ragged margins. Apertural collar 4.5 µm deep.

Type locality: Western Australia, southern Officer Basin, Vimy Resources' Mulga Rock tenement, drill hole NNA-5507 at 52–53 m, Late Eocene.

Comparison and discussion: Banksieaeidites cooksonii is similar to *B.* sp. A Dudgeon 1983, but differs in possessing a much thicker nexine mesoporially when compared to the sexine. The nexine in *B.* sp. A. Dudgeon is significantly thicker at the apertures than in *B. cooksonii. Banksieaeidites cooksonii* also resembles *B. elongatus* Cookson 1950 but differs in being smaller in size and generally biconvex rather than plano-convex. The larger aperture size range for *B. cooksonii* differentiates it from both *B. elongatus* and *B. minimus*. *Banksieaeidites cooksonii* is closer in size to *B. minimus* but possesses a deeper collar and a much thicker exine on average.

Banksieaeidites davidsonii sp. nov. (Plate B2, Figs A–O)

Etymology: Named for Charlotte's grandfather, Leslie Davidson, for the support and encouragement that was instrumental in her undertaking this project.

Diagnosis (TLM): Pollen diporate, anisopolar; outline in equatorial view asymmetrically elliptical with truncated ends, amb plano-convex, occasionally biconvex, dependent on grain orientation. Exine 1.75–3 µm, thickening to 2–3.5 µm at the aperture, distinctly stratified; nexine thicker than sexine. Exine thinner in mature specimens. Nexine thins abruptly prior to apertural collar, thickening over the collar. Sexine thins to apertures; psilate in most cases, with rare specimens appearing microreticulate. Apertures lalongate with ragged margins, 6–12 µm in diameter, widening with maturity, apertural collar 3–6 µm deep.

Sculptural detail (SEM): Surface rugulo-tectate perforate; rugulae 1.23–3.59 µm in length, 0.41–0.67 µm wide, relatively low relief; perforations mostly circular, elongate oval shaped where tectum sunk between perforations; circular perforations 0.04–0.3 µm in diameter, elongate perforations 0.4–1.23 µm long, 0.05–0.78 µm apart, larger and closer together towards the apertures. Surface of rugulae smooth to slightly nanorugulate.

Dimensions: Length 30 (34) 39 µm, width 19 (22) 24 µm (22 specimens)

Holotype: (Plate B2, Figs A–C) Pollen diporate, anisopolar; outline in equatorial view asymmetrically elliptical with truncated ends, amb plano-convex. Exine 2

µm, thickening to 2.5 µm at the aperture, distinctly stratified; nexine significantly thicker than sexine. Nexine thins to <0.5 µm in notch 1.5 µm wide prior to the apertural collar, before thickening over the apertural collar. Sexine psilate. Aperture lalongate with ragged margins, 9.5 µm in diameter; apertural collar 5 µm deep.

Paratype: (Plate B2, Figs E–H) Pollen diporate, anisopolar; outline in equatorial view asymmetrically elliptical with truncated ends, amb plano-convex. Exine 2 µm, thickening to 3.5 µm at the apertures, distinctly stratified; nexine significantly thicker than sexine. Nexine thins to 1 µm prior to apertural collar, thickening over apertural collar. Sexine reticulate. Aperture lalongate with ragged margins, 10 µm in diameter; apertural collar 5 µm deep.

Type locality: Western Australia, southern Officer Basin, Vimy Resources' Mulga Rocks tenement, drill hole CD-1-763 54.9–55 m and NNA-5510 43–44 m.

Comparison: *Banksieaeidites davidsonii* resembles *B.* sp. A Dudgeon 1983 but lacks the baculate exine. It also resembles *B. elongatus* Cookson in that it is generally plano-convex, but the amb is distinctly shorter. The ratio of length to width also distinguishes the two, with *B. elongatus* thinner relative to its length. *Banksieaeidites davidsonii* is more commonly psilate under light microscopy, rather than microrugulate as in *B. cooksonii*. This also serves to differentiate it from *B. elongatus*, in that *B. elongatus* possesses a clearly defined reticulum. Specimens of *B. elongatus* described by Memon (1976) from the Pidinga Formation in South Australia are distinctly smaller than specimens of *B. davidsonii*, with much smaller apertures. In SEM, the perforations (described as fovea by Memon 1976) of *B. davidsonii* reach a larger maximum size, and are much more randomly distributed than in *B. elongatus*.

9.6.2 Modern material

Subtribe Banksiinae

Banksia L. f.

Provisional diagnostic characters

Banksia pollen studied to date is diporate and oval, cylindrical or crescentic in shape (Johnson and Briggs 1975). Sedgley *et al.* (1993) considered length, diameter, and

length:diameter ratio, but did not take into account sculpture, aperture or wall structure. In describing the sporotype *Banksieaeidites,* Cookson (1950) listed the additional characteristics of sub-isopolarity and an ectonexine that thickens around the apertures. Martin (1982) noted that pollen of subtribe Musgraveinae has a constricted aperture that is distinct from pollen of subtribe Banksiinae.

Banksia ashbyi Baker f. (Plate B3, Figs A–H)

Description (TLM): Pollen diporate, subisopolar; amb in equatorial view elliptical to slightly crescent shaped with ends sharply truncated; planoconvex to slightly concavo-convex, rarely slightly biconvex. Exine 1.25–2.5 µm, thickening to 2–4 µm at apertures, indistinctly to distinctly stratified; nexine significantly thicker than sexine. Nexine thins by <0.5–0.5 µm prior to the apertural collar, either gradually or in a discrete notch. Sexine psilate to microrugulate depending on maturity. Tectum and infratectum indistinguishable. Apertures lalongate, 13–21 µm in diameter with slightly ragged margins; apertural collar present, 3–6 µm deep.

Sculptural detail (SEM): Tectum rugulo-tectate perforate; shallow depressions containing perforations defining rugulae; rugulae 0.88–3.44 µm long, 0.34–0.8 µm wide, occasionally as wide as long; perforations circular, 0.05–0.1 µm wide, 0.1–0.54 µm apart, occasionally with tectum sunk between perforations forming troughs 0.27–0.8 µm long along edges of rugulae. Surface of rugulae appears smooth to nanoscabrate at lower magnifications, nanoscabrate at higher magnifications.

*Dimension*s: Length 45 (51.5) 58 µm, width 23 (29) 36 µm

Banksia attenuata R. Br. (Plate B3, Figs 3I–Q)

Description (TLM): Pollen diporate, subisopolar; amb in equatorial view elliptical to slightly crescent shaped with ends truncated, mostly planoconvex, with rare grains asymmetrically biconvex and concavo-convex specimens, dependent on orientation. Exine 1.25–2 µm, thickening to 2–4 µm at the apertures, distinctly stratified, except where obscured by apertural collar. Nexine significantly to slightly thicker than sexine, nexine thins in a <0.5–0.75 µm wide notch at the apertural collar, thinning by <0.5–1.25 µm. Sexine constant to slightly thickening towards aperture; psilate. Tectum and infratectum distinguishable in only one

grain, with tectum half the thickness of the infratectum. Apertures circular to lalongate, 9–19 µm in diameter with ragged margins; apertural collar present, 3–5 µm deep.

Sculptural detail (SEM): Tectum rugulo-tectate perforate; rugulae margins defined by perforations; rugulae appear flat topped, 0.75–3.04 µm long, 0.31–0.8 µm wide, rarely as wide as long; perforations circular, 0.03–0.07 µm in diameter, 0.14–0.75 µm apart, occasionally with tectum sunk between perforations forming troughs 0.24–0.64 µm long along edges of rugulae. Rugulae surfaces appear smooth at lower magnification, nanoscabrate at higher magnification.

Dimensions: Length 36 (42) 48 µm, width 23 (25) 33 µm

Banksia baxteri R. Br. (Plate B4, Figs A–J)

Description (TLM): Pollen diporate, isopolar; amb in equatorial view oval to elongated oval with truncated ends; ranging from symmetrically to asymmetrically biconvex to planoconvex. Exine 2.5–3.25 µm, thickening to 3.25–5 µm at apertures, distinctly stratified. Nexine significantly thicker than sexine, with sexine reaching a maximum thickness of 1 µm; nexine occasionally thins in notch up to 0.5 µm prior to the apertural collar. Sexine distinctly rugulate. Tectum and infratectum indistinguishable. Apertures lalongate, 14.5–33 µm in diameter with ragged margins. Apertural collar present, 6–10.5 µm deep.

Sculptural detail (SEM): Tectum distinctly rugulo-tectate perforate, some rugulae more prominent than others, seeming interwoven in immature specimens, relief decreasing in mature specimens. Rugulae straight to curved, 1.06–11.52 µm in length, 0.9–1.6 µm wide. Perforations along rugulae margins circular, 0.04–0.13 µm in diameter, 0.06–0.65 µm apart; occasionally tectum sunken between 2–4 perforations forming troughs 1.07–1.44 µm long. Surface of rugulae smooth to nanoscabrate.

Dimensions: Length 60 (42.5) 86 µm, width 38 (44) 64 µm

Banksia burdettii Baker f. (Plate B5, Figs A–H)

Description (TLM): Pollen diporate, isopolar, amb in equatorial view ellipsoidal, circular in more mature specimens, with truncated ends; mostly symmetrically biconvex, occasionally asymmetrical. Exine 1–2 µm, thickening to 2–4 µm at apertures, distinctly stratified. Nexine significantly thicker than sexine at

apertures, thinning to a slight to distinct notch prior to the apertural collar. Mesoporially, sexine equal to or slightly thicker than nexine. Sexine thins to the aperture; microrugulate, rugulate in some immature specimens. Tectum and infratectum indistinguishable. Apertures lalongate, 13–21 µm in diameter with ragged margins. Apertural collar present, 4–6 µm deep.

Sculptural detail (SEM): Tectum rugulo-tectate perforate with broad, low relief rugulae, flattening in more mature specimens. Rugulae 1.44–4.8 µm long, 0.4–1.28 µm wide; circular perforations along margins of rugulae, 0.05–2 µm in diameter, widening in mature specimens, 0.16–0.8 µm apart. Surface of rugulae smooth.

Dimensions: Length 41 (44.5) 49 µm, width 32 (38) 42 µm

Banksia grandis Willd. (Plate B5, Figs 5I–P)

Description (TLM): Pollen diporate, isopolar, amb in equatorial view oval to almost circular with truncated ends, mostly biconvex, some grains asymmetrically biconvex. Exine 1.25–2.75 µm, thickening to 2.25–4 µm at apertures. Nexine significantly to slightly thicker than exine. Sexine appears psilate to microrugulate, tectum and infratectum indistinguishable. Apertures circular to lalongate, 10–18.5 µm in diameter with ragged margins. Apertural collar present, 3–6 µm deep.

Sculptural detail (SEM): Tectum rugulo-tectate perforate with incised perforations delineating margins of rugulae. Rugulae 1.12–2.56 µm long, 0.27–0.68 µm wide; distribution of perforations fairly uniform, most approximately 0.3 µm apart, though ranging from 0.06–0.8 µm apart. Perforations circular 0.05–0.07 µm in diameter, tectum sunk between two perforations on rare occasions forming troughs 0.25–0.32 µm long. Surface of rugulae nanorugulate, parallel to direction of rugulae.

Dimensions: Length 39 (43) 47 µm, width 29 (32) 41 µm

Banksia menziesii R. Br. (Plate B6, Figs A–H)

Description (TLM): Pollen diporate, subisopolar, amb in equatorial view semi-circular to oval with truncated ends; planoconvex to symmetrically and asymmetrically biconvex. Exine 1.5–4 µm, thickening in most cases to 2.5–4 µm at apertures, though several grains show consistent thickness between the mid-

grain and aperture. Nexine thicker than sexine, thickening to the aperture, but thinning prior to apertural collar, occasionally to a distinct notch with the nexine absent. Sexine either consistent or thinning to the aperture; psilate to microrugulate. Tectum equal to infratectum where distinguishable. Apertures circular to lalongate, 15.5–22 µm in diameter with slightly ragged margins. Apertural collar present, 4–5.5 µm deep.

Sculptural detail (SEM): Rugulo-tectate perforate surface; rugulae mostly curved, some straight, 1.4–2.6 µm long, 0.4–0.6 µm wide; perforations along margins of rugulae, circular, 0.04–0.05 µm in diameter, 0.24–0.52 µm apart, slightly sunken tectum causing occasional pairing of perforations in shallow troughs 0.3–0.4 µm long. Surface of rugulae smooth at lower magnification, smooth to nanoscabrate at higher magnification.

Dimensions: Length 49 (55) 63 µm, width 34 (37) 42 µm

Banksia occidentalis R. Br. (Plate B6, Figs I–R)

Description (TLM): Pollen diporate, isopolar, amb in equatorial view oval with truncated ends, symmetrically biconvex. Exine 1–2 µm, thickening to 1.5–2.5 µm at apertures. Nexine thicker than sexine, nexine mostly consistent across grain, thinning in a weak to distinct notch prior to apertural collar, in rare cases where notch is undeveloped nexine thins. Sexine thickens to aperture; microrugulate to psilate. Tectum and infratectum indistinguishable. Apertures circular to lalongate, 7–11.5 µm in diameter with discrete margins. Apertural collar present, 1.75–3 µm deep.

Sculptural detail (SEM): Tectum perforate, with circular perforations shallow and consistent over grain, 0.12–0.96 µm apart and 0.06–0.12 µm wide; surface between perforations appears smooth at lower magnifications, nanoscabrate at higher magnifications.

Dimensions: Length 24 (26) 28 µm, width 19 (21) 22 µm

Banksia tricuspis Meisn. (Plate B7, Figs 7A–J)

Description (TLM): Pollen diporate, isopolar, amb in equatorial view oval with truncated ends, mostly symmetrically to asymmetrically biconvex, rarely planoconvex. Exine 1–2 µm, thickening to 2–3 µm at apertures, exine stratification distinct in immature grains, indistinct in some mature grains. Nexine

significantly thicker than sexine in immature grains, thinner than sexine in mature grains. Nexine thickens to aperture. Sexine consistent or thickening to aperture; microrugulate. Tectum and infratectum indistinguishable in all grains. Apertures circular to slightly lalongate in immature grains, lalongate in mature, 4–13 µm in diameter with ragged margins. Apertural collar present, 2.5–4 µm deep.

Sculptural detail (SEM): Immature specimens (Fig. 7F–H): surface rugulate, rugulae defined by perforations; rugulae 0.8–1.76 µm in length, 0.34–0.64 µm wide; perforations circular, 0.05–0.1 µm wide, 0.14–0.49 µm apart, occasionally with tectum sunk between perforations forming troughs 0.29–0.39 µm long; surface of rugulae appears smooth at lower magnifications, slightly wrinkled at higher magnifications. Mature specimens (Fig. 7I, J): surface rugulate with interwoven rugulae interspersed with perforations; definition of rugulae by perforations weaker than in immature specimens; rugulae 1.44–3.68 µm long, 0.2–0.55 µm wide; perforations circular to lalongate, with intermediates reminiscent of two circular perforations joined together, 0.04–0.17 µm wide, 0.12–0.52 µm apart; surface nanorugulate parallel to rugulae, 0.09–0.34 µm long and 0.02–0.06 µm wide.

Dimensions: Length 28 (31) 38 µm, width 16 (18) 25 µm

9.7 Discussion

9.7.1 Variation in extant species

The *Banksia* pollen described herein share numerous morphological characteristics that make them distinct from other groups of Proteaceae, yet also possess features that allow them to be distinguished from one another.

Size: The most obvious difference between species is a broad range in size (Table 9.1). The smallest, *B. occidentalis,* is on average 25.93 µm long and 20.63 µm wide. The largest, *B. baxteri*, averages 71.23 µm in length with the largest grain measured at 86 µm. The median length of species studied is 42.25 µm.

Amb: The shape of the amb in *Banksia* seems to be consistent within species. Though the shape may vary on the basis of orientation of the grain when fixed in 'Eukitt', the observation of 30 grains has allowed for the determination of overall curvature. One species, *B. ashbyi*, is distinctly concavo-convex. This feature was also observed, though rarely, in *B. attenuata*. Others (*B. attenuata, B. baxteri* and *B. menziesii)* vary between plano-convex and biconvex. The remainder (*B. burdettii, B. grandis, B. occidentalis* and *B. tricuspis)* are solely biconvex with no grain curvature. The relationship of length to width relates to the distinctive shapes of individual pollen grains, with a low value (e.g. *B. burdettii* and *B. occidentalis*) defining a grain that is almost circular in shape (Fig. 5D, L), and a high value for the more elongated shaped species such as *B. ashbyi* and *B.attenuata* (Fig. 3A–C, J–L).

Exine: Exine thickness (Table 9.1) remained relatively consistent, with only 1.25 µm difference between the thickest and thinnest interapertural wall measurements. However, with the raw measurements it is obvious that *B. baxteri* will have a thicker exine when compared against *B. occidentalis* because *B. baxteri* has a much larger grain size overall. The calculation of ratios (width:wall thickness) more directly shows the relationship of width to the overall grain size. These ratios (9.2) give a broader range of 12.21 to 21.95, with *B. burdettii* (44.63 µm average length) possessing the thinnest walls relative to its size. The nexine of all grains studied thickened at the aperture, as observed by Cookson (1950). Not noted by Cookson, is a thinning of the nexine prior to the aperture at the start of the apertural collar, much like that seen in *Xylomelum* Sm. pollen (Milne 1994). This thinning occurs on a spectrum from gradual thinning (Fig. 3K) over a maximum distance of 2 µm to a distinct notch less than, or equal to, 0.5 µm (e.g. Fig. 3B). The degree to which the nexine thins is also variable, with some grains showing a reduction of half and others in which the nexine is entirely absent (e.g. Fig 5I). The development of the notch does not appear to be consistent within species and variation may be due to the angle at which the wall is viewed, or the maturity of individual grains.

Table 9.1 Average of measurements for extant *Banksia* and fossil *Banksieaeidites* pollen. Italicised values indicate a relationship between *Banksieaeidites cooksonii* and underlined values a relationship to *B. davidsonii*.

Extant species	Length	Width	Aperture Width	Exine								Collar Depth
				Total (Aperture)	Total (Inter-aperture)	Nexine (Aperture)	Nexine (Inter-aperture)	Sexine (Aperture)	Sexine (Inter-aperture)	Tectum	Infratectum	
Banksia* subgenera *Banksia	**52.93**	**35.05**	**17.14**	**3.23**	**2.14**	**2.52**	**1.42**	**0.64**	**0.72**	**-**	**-**	**5.21**
Banksia ashbyi	51.63	28.37	15.96	2.86	1.74	2.42	1.28	0.44	0.48	-	-	4.80
B. attenuata	42.00	26.07	12.19	2.72	1.73	1.94	1.22	0.43	0.52	0.25	0.50	3.61
B. baxteri	71.23	46.70	21.37	4.36	2.78	3.68	2.10	0.68	0.68	-	-	7.90
B. burdettii	44.63	37.50	18.17	2.78	1.71	2.02	0.80	0.77	0.89	-	-	4.67
B. menziesii	55.17	36.63	18.00	3.45	2.73	2.53	1.72	0.89	1.01	0.51	0.51	5.09
Banksia* subgenera *Spathulatae	**33.73**	**24.59**	**9.74**	**2.35**	**1.68**	**1.83**	**1.13**	**0.50**	**0.53**	**-**	**-**	**3.33**
B. grandis	42.90	33.40	13.10	2.85	1.88	2.35	1.35	0.44	0.51	-	-	4.65
B. occidentalis	25.93	*20.63*	8.83	1.85	1.53	1.27	0.97	0.58	0.56	-	-	2.21
B. tricuspis	*32.37*	19.73	7.28	2.35	1.62	1.88	1.08	0.48	0.53	-	-	3.13
Fossil species												
Banksieaeidites arcuatus	20.47	11.49	3.01	0.93	0.90	0.76	0.72	0.28	0.27	-	-	1.48
B. cooksonii	*30.32*	*23.40*	*10.94*	*3.10*	*2.01*	*2.65*	*1.40*	*0.45*	*0.61*	*0.28*	*0.47*	*4.31*
B. davidsonii	34.45	21.60	9.15	3.05	2.34	2.73	1.45	0.44	0.79	-	-	4.25

Aperture: The size of the apertures relative to the total grain size varied between species. Aperture width (Table 9.1) ranged from 7.28 µm (*B. tricuspis*) to 21.27 µm (*B. baxteri*). The length:aperture width ratio (Table 9.2) showed that *B. tricuspis* had the smallest apertures relative to the size of the amb (4.83), while *B. burdettii* had the largest (2.48), followed by *B. occidentalis* (2.99). Apertural collar depths (Table 9.1) ranged from 2.21 µm (*B. occidentalis*) to 7.90 µm (*B. baxteri*) in diameter. Length:collar depth (Table 9.2) supports the observation that the smallest pollen grains (*B. occidentalis)* on average possessed the smallest collar relative to its size, and the largest (*B. baxteri*) had the deepest collars.

Table 9.2 Average descriptive ratios for pollen morphology of extant *Banksia* and fossil *Banksieaeidites* pollen. Italicised values indicate a relationship between *Banksieaeidites cooksonii* and underlined values a relationship to *B. davidsonii*.

Extant species	Length to Width	Width to Exine	Length to Aperture Width	Length to Collar Depth
Banksia* subgenera *Banksia	**1.54**	**16.69**	**3.33**	**10.56**
Banksia ashbyi	1.84	16.29	3.32	10.89
B. attenuata	1.62	15.04	4.32	11.93
B. baxteri	1.54	16.78	3.45	*9.21*
B. burdettii	1.19	21.95	2.48	9.72
B. menziesii	1.51	13.40	3.08	11.07
Banksia* subgenera *Spathulatae	***1.40***	**14.49**	**3.74**	**10.64**
B. grandis	*1.29*	17.73	3.40	9.46
B. occidentalis	1.26	13.53	*2.99*	12.02
B. tricuspis	1.66	*12.21*	4.83	10.45
Fossil species				
Banksieaeidites arcuatus	1.79	12.70	7.19	15.43
B. cooksonii	*1.30*	*11.66*	*2.87*	*7.27*
B. davidsonii	1.60	9.24	3.83	8.34

Sculptural detail: With light microscopy, differences in sculpture were hard to differentiate. Many of the pollen grains studied were microrugulate (*B. burdettii, B. tricuspis)* to psilate (*B. attenuata*), with both observed in several species depending on grain maturity (*B. ashbyi, B. grandis, B. menziesii B, occidentalis*). *Banksia baxteri* and *B. burdettii* have a distinctly rugulate sculpture, though only in immature grains for *B. burdettii*. Scanning electron microscope images show that all species

studied are tectate perforate, with a large difference in perforation size and distribution. In rugulo-tectate perforate specimens, the size and distribution of rugulae were distinctly different between species. Finer surface structures, viewed at higher magnifications, were also characteristic of individual species.

9.7.2 Variation between subgenera Banksia *and* Spathulatae

The eight *Banksia* species studied were separated in to subgenera and averages calculated for each of the measureable characters (Table 9.1 and 9.2). Though the sample size in this study is relatively small, some differences between the subgenera can be seen, but there are many similarities.

Amb: A variation of morphologies is apparent in *B.* subgen. *Banksia* with the amb shape ranging from concavo-convex to planoconvex to asymmetrically and symmetrically biconvex. Species from *B.* subgen. *Spathulatae* in this study are symmetrically biconvex with rare asymmetrical biconvex grains.

Sculptural detail: The microrugulate sculpture in TLM appears to be shared across the two subgenera. Under SEM, pollen from both subgenera have rugulo-tectate perforate sculpture and circular perforations that may form troughs. *Banksia* subgen. *Banksia* sculptures include rugulate with a nanoscabrate surface. The sculpture of *B.* subgen. *Spathulatae* species range from psilate-perforate with a nanoscabrate surface (*B. occidentalis*) to rugulate with a nanorugulate surface to the rugulae.

9.7.3 Variation based on maturity

Both mature and immature grains of fossil species occur in the fossil record (e.g. Milne, 1994). Most anthers from the modern species collected for study were mature, but one or two slightly immature anthers were included for each species. Therefore, differences in many of the characters listed above may also be due to the maturity of grains measured. Distinct morphological differences between immature and mature grains include amb shape, mesoporial exine thickness, aperture size and the development of the collar (Table 9.3).

Amb: The amb will increase in width relative to length as pollen grains mature. The ratio of length to width also helps define the changes in grain shape as pollen grains mature. The width of grains in this study increased relative to the length, thus decreasing this ratio, on average, from 1.52 in mature grains to 1.40 in immature grains.

Exine: On average, the interapertural wall thickness decreases from 2.04 to 1.72 µm from immature to mature grains. The comparative ratio of grain width to wall thickness shows a significant increase from 15 to 21.51, on average, between immature and mature grains. This indicates a dramatic thinning of the exine as the pollen grains expand with maturity.

Aperture: Aperture width increases by 4.23 µm on average. Length:aperture width shows the degree to which the aperture is opened relative to the overall size of the grain. On average, this ratio is 3.72 in immature grains, compared to 2.79 in mature grains. The most distinct difference in relative aperture size based on maturity is observed in *B. tricuspis*, where the ratio decreases from 5.27 to 3.40. Apertural collar depth, on average, is reasonably consistent overall, increasing from 4.48 to 4.55 µm from immature to mature specimens. Averages for some species differ markedly. The collar of *B. attenuata* increases from 3.54 to 4.06 µm between immature and mature. However, the ratio between collar depth and grain length shows that, despite the raw measurement increasing with maturity, the relative size of the collar to the overall grain length actually decreases.

Sculptural detail: Sculptural changes are also observed between mature and immature grains. The overall increase in size of grains as they mature has the effect of 'spreading out' sculptural elements. For example, in TLM, the sculpture of Banksia *burdettii* changes from rugulate to microrugulate as the grain expands with maturity. Viewed under SEM, the perforation shape in *B. tricuspis* changes as grains mature, with circular perforations joining to create more lalongate features. A similar change is observed in the sculptural detail of *Banksieaeidites cooksonii*.

Table 9.3 Comparative values for mature and immature morphology in extant *Banksia* pollen.

Species	Length	Width	Aperture Width	Interapertural Exine Thickness	Collar Depth	Length to Width	Width to Exine Thickness	Length to Aperture Width	Length to Collar Depth
Banksia ashbyi									
Immature	49.71	25.88	13.93	1.91	4.71	1.93	14.00	3.62	10.68
Mature	54.15	31.62	18.62	1.52	4.92	1.72	21.08	2.94	11.16
B. attenuata									
Immature	41.14	24.67	11.66	1.68	3.54	1.67	15.27	4.76	11.93
Mature	44.00	29.33	15.28	1.47	4.06	1.51	20.12	2.93	11.38
B. baxteri									
Immature	68.73	42.59	18.90	3.02	7.77	1.61	14.31	3.67	9.03
Mature	78.13	58.00	28.19	2.13	8.25	1.35	27.81	2.85	9.68
B. burdettii									
Immature	44.77	37.04	17.88	1.74	4.73	1.21	21.68	2.52	9.56
Mature	45.00	40.50	20.00	1.50	4.25	1.11	28.79	2.26	10.71
B. grandis									
Immature	42.43	31.57	11.60	2.04	4.71	1.35	15.79	3.72	9.26
Mature	44.00	37.67	16.61	1.53	4.50	1.17	25.58	2.67	9.93
B. menziesii									
Immature	54.96	35.96	17.62	2.70	5.09	1.41	13.98	3.13	11.00
Mature	56.20	40.00	19.90	2.90	5.10	1.53	14.60	2.83	11.44
B. occidentalis									
Immature	25.92	20.50	8.54	1.55	2.24	1.25	13.45	3.07	11.87
Mature	26.00	21.50	10.75	1.38	2.00	1.28	16.08	2.43	13.00
B. tricuspis									
Immature	31.30	18.52	6.17	1.70	3.07	1.70	11.56	5.27	10.36
Mature	35.86	23.71	10.79	1.36	3.36	1.51	17.98	3.40	10.77
Average									
Immature	44.87	29.59	13.29	2.04	4.48	1.52	15.00	3.72	10.46
Mature	47.92	35.29	17.52	1.72	4.55	1.40	21.51	2.79	11.01

9.7.4 Affiliates of fossil species

Banksieaeidites pollen is well-known from sediments of Palaeogene age in southern Australia, with the most commonly reported species being *B. arcuatus* (Fig. 1A–F), a diminutive and morphologically simple species that has been aligned with the Proteaceae subtribe Musgraveinae (Christophel 1984). The two Musgraveinae species, *Austromuellera* and *Musgravea*, are currently restricted to rainforest in northern Queensland. The pollen characters of *B. cooksonii* sp. nov. and *B. davidsonii* sp. nov. are distinctly *Banksia*-like in that they possess relatively thick walls, expanded apertures, a thinning of the nexine at the apertural collar and a tectate perforate sexine.

Banksieaeidites cooksonii shares the microrugulate sculpture, under light microscopy, of most of the extant species studied. The average length is closest to that of *Banksia tricuspis* and the average width to that of *B. occidentalis*. A mostly biconvex amb, with very rare planoconvex, is similar to that of *B. burdettii*, *B. grandis* and *B. tricuspis*. The amb shape is mostly reminiscent of that of *B. grandis* and *B. occidentalis*, as supported by a length:width value of 1.30 as compared to 1.29 and 1.26 respectively. The ratio of width to wall thickness is relatively low (11.66), indicating an exceptionally thick wall compared to the modern species in this study. The closest value is that of *B. tricuspis* at 12.21. The size of the aperture in regard to grain length (length:aperture width of 2.87) is at the lower end of the scale compared against that of modern species, indicating a relatively large aperture. The length:aperture is closest to that of *B. occidentalis* (2.99) and the length:collar depth of 7.27 is distinctly low, outside the range given by the species included in this study. This indicates that *B. cooksonii* has a distinctively large collar when compared against the modern species in this study. *Banksieaiedites cooksonii* shares the majority of its characteristics with species contained within *Banksia* subgen. *Spathulatae.*

Banksieaeidites davidsonii, in most cases, appears psilate under light microscopy, though rare microreticulate specimens were observed. The average length and width

is closest to that of *B. tricuspis*. The amb shape is mostly reminiscent of that of *B. attenuata,* as supported by a length:width value of 1.60 compared to 1.62. *Banksieaeidites davidsonii* is mostly planoconvex, with rare biconvex specimens, much like *B. attenuata, B. baxteri* and *B. menziesii*. The size of the aperture in regards to grain length (length:aperture width of 2.87) is at the lower end of the scale compared against that of modern species, indicating a relatively large aperture. The relative thickness of the interapertural wall is even higher than that of *B. cooksonii*, with a width:wall thickness ratio of 9.24. The length:aperture is closest to that of *Banksia baxteri* (3.45), but at 3.83 *Banksieaeidites davidsonii* possesses the narrowest aperture relative to length. The length:collar depth of 8.34 is distinctly low, outside the range given by the species included in this study. This indicates that *B. davidsonii* also has a distinctively large collar when compared against modern species. *Banksieaeidites davidsonii* shares characteristics with species contained within both *Banksia* subgen. *Banksia* and *B.* subgen. *Spathulatae.* However, more of its descriptive ratios are closer to those of *B.* subgen. *Banksia*, with raw measurements being much more variable across individual species, particularly size. The mostly plano-convex nature of *B. davidsonii* is also similar to that of *B.* subgen. *Banksia.*

Fossil leaves of *Banksia* are known from sediments of similar age (late Eocene) in Western Australia, and show morphology that is distinctly sclerophyllous and, in one case, xeromorphic (Carpenter *et al.* 2015). A new species has been recognised, from cuticle, from nearby sediments at Zanthus that are also of Late Eocene age (R. Carpenter and L. Milne pers. comm.).

9.7.5 Geological association

Banksieaeidites pollen at Mulga Rocks occurs predominately in silt and clay. The highest percentages (ranging from 3.5–7%) are found in dark brown to black silts and lignitic clays, sediments that are associated with low energy swamp to lagoonal environments. Lower percentages (from 0.5–2.5%) occur in dark brown claystone with a variable sand content. Both species are rare in sediments ranging from medium to dark brown siltstones, sandy clays and siltstones and clayey sands. In all

instances these sediments are heavily carbonaceous and are still likely to represent low energy environments, possibly the decreasing energy associated with river bends.

The majority of *Banksia* today grow in sandy soils. However, several species grow in swamp to near-swamp environments. In Western Australia, these are *Banksia littoralis, B. occidentalis* and *B. quercifolia*; in eastern Australia, *B. ericifolia, B. paludosa* subsp. *paludosa* and *B. robur*.

9.8 Conclusion

The description of two new *Banksieaeidites* species and their comparison to the morphology of pollen of extant *Banksia* has revealed that distinct characters exist that are shared between living and fossil species. These morphological characters are distinct from those described for *Banksieaeidites arcuatus*, the fossil species aligned with Musgraveinae. Previous and ongoing macrofossil work has shown that leaves with characters unequivocally those of *Banksia* indicate that the genus was growing in the Late Eocene vegetation of Western Australia. Many of the macrofossils of *Banksia* and *Banksieaephyllum* have sclerophyllous features, and one is distinctly xeromorphic. The relatively prominent presence of two new *Banksieaeidites* species in the Mulga Rocks sediments suggests the palaeovegetation at this site likely contained a distinct scleromorphic component. The systematic description of two new species from Mulga Rocks indicates a greater diversity of *Banksia* in the late Eocene than previously reported, as the only other formally described representatives are *Banksieaeidites elongatus* and *B. minimus* (Cookson 1950), subsumed into one species by Stover and Partridge (1973). The occurrence of *Banksieaeidites* pollen at Mulga Rocks in carbonaceous silt and clay lithologies indicates that the plant producing these fossil species may have been growing within a swampy environment at the study site.

Further research into the morphology of species previously assigned to *Dryandra*, and that of the extant species of *Musgraveinae,* is required to fully assess the morphological characters that define *Banksia*. A larger sample size is also required to

determine the validity of differences observed between *Banksia* subgen. *Banksia* and *B.* subgen. *Spathulatae*.

10. Conclusions

Diverse and well-preserved palynofloras have been recovered from eight drill holes from the 'Narnoo Palaeovalley' in the southern Officer Basin, WA. Seventy five sediment samples, of which fifty eight were productive, were collected and analysed from eight drill holes in a cross section over Vimy Resources' Princess and Ambassador uranium deposits. A total of 163 previously described species of spores and pollen have been identified and 36 undescribed species are reported. Eighteen new species are described in detail; *Banksieaeidites cooksonii, B. davidsonii, Myrtaceidites corymbioides, Proteacidites ambassadatus, P. colubrimodus, P. crochetaria, P. microspinosus, P. narnooensis, P. polygonalis, P. protrudens, P. rickmanii, P. tesselaria, P. vaga, Rhoipites oralongii, R. orbiculatus, Tricolpites discoides, T. occultum* and *T. reticularis.*

The two new species of *Banksieaeidites, B. cooksonii* and *B. davidsonii*, have been described using both TLM and SEM. Morphological comparisons with eight extant species; *Banksia ashbyi* Baker f., *B. attenuata* R. Br., *B. baxteri* R. Br., *B. burdettii* Baker f., *B. grandis* Willd., *B. menziesii* R. Br., *B. occidentalis* R. Br. and *B. tricuspis* Meisn., confirm that the two new species can be confidently aligned with extant *Banksia*, and are distinct from *Banksieaeidites arcuatus*, the fossil species aligned with Musgraveinae.

The stratigraphy of the drill holes studied has been correlated with Vimy Resources' informal lithostratigraphic scheme. The units present varied in thickness across the transect, with notable thicknesses of sand occurring in the southwest, and Dc1 (carbonaceous clay to lignitic clay) limited to the northeast end. The boundary between the mostly sand-rich with minor clay sub-units of Vimy's Unit D and the lignitic to carbonaceous sands of Unit E, is distinguished by the distribution of individual pollen species; the last appearance of *Proteacidites ivanhoensis, P.* cf. *P. pseudomoides* sp. 1, *P, microverrucatus, P. leightonii, P. colubrimodus* and *P. kopiensis* at the top of Unit D, and the first appearance at the base of unit E of *Anacolosidites luteoides, Arecipites waitakiensis, Parvisaccites catastus, Proteacidites punctiporus, P. tesselaria, Rhoipites aralioides* and *Triporopollenites*

delicatus. The E1 and E2 intervals can be distinguished from each other based on an increase in *Haloragacidites harrisii* into E2, and by the two species restricted to the E2 interval: *Podocarpidites puteus* and *Proteacidites crochetaria*.

The Mulga Rock palynofloras are dated as late Eocene (Middle *Nothofagidites asperus* Zone equivalent of the Murray Basin, Macphail 1999) based on the presence of *Aglaoreidia qualumis, Anacolosidites sectus, Proteacidites confragosus, P. tuberculatus, Rhoipites sphaerica, Santalumidites cainozoicus, Sapotaceoidaepollenites rotundus, Tricolpites incisus* and *T. thomasii.* Some species present are not recorded in the late Eocene of the Gippsland and Murray basins. . *Proteacidites alveolatus* and *Psilastephanocolporites micus,* are restricted in the Gippsland Basin to the early Eocene Lower *N. asperus* Zone and the early Miocene *Proteacidites tuberculatus* Zone (Stover and Partridge 1973, Partridge 1976) respectively. They were also recognised in late Eocene sediments at Zanthus (Milne 1988). *Proteacidites tuberculatus* was identified in the Mulga Rock palynoflora, a first for WA, but does not appear in the Gippsland Basin until the Upper *N. asperus* Zone of Stover and Partridge (1973) now considered of early Oligocene age (Partridge 2006).

The largest percentages of *Proteacidites* spp. are associated with the sand intervals Dc2 and Dw3, and were likely present in the local vegetation. *Haloragacidites harrisii,* aligned with modern Casuarinaceae, is highest in the clay units (Dc3, Dc1 and Dw4) of Unit D, and may have been local to the floodplain environment interpreted for these units, though this conclusion is hard to make as modern Casuarinaceae is wind pollinated. The plants producing *H. harrisii* could have contributed similar percentages from the hinterland. The variable presence of *H. harrisii* and *Proteacidites* spp. in the pollen assemblages, and their correlation with lithological intervals, suggest that the Mulga Rock sediments studied were deposited in a meandering river system within a large palaeovalley; with associated point bar, flood plain and swamp environments.

The Mulga Rock assemblages are variably dominated by *Haloragacidites harrisii, Nothofagidites* spp. and *Myrtaceidites* spp. indicating variation in the palaeovegetation across the transect. Plants producing *H. harrisii* and *Nothofagidites*

spp. were likely wind-pollinated, as their modern counterparts are today, and could have been present in the hinterland. The *Myrtaceidites*-dominated assemblages are associated with a high occurrence and diversity of proteaceous pollen, suggesting that the palaeovegetation at Mulga Rock contained a significant sclerophyllous component. High percentages of *Myrtaceidites* spp without associated *Proteacidites* (particularly those aligned with genera occupying heath and woodland areas today) were interpreted to represent a wet sclerophyll environment. The two new *Banksieaeidites* spp. described also indicate a sclerophyllous community was present. In addition, *Banksia* macrofossils reported from the late Eocene of WA show evidence of sclerophylly, and one of xeromorphy. These assemblages suggest that more of the late Eocene vegetation of WA may have been woodland, dry forest and/or heathland than previously thought. *Nothofagus* is known to produce substantial amounts of pollen and occurs in species-poor forests today. The high number and diversity of other genera and species present in the Mulga Rock palynoflora suggests *Nothofagus* was unlikely to have been prominent in the local vegetation. This assemblage is irreconcilable with the presence of a mesothermal *Nothofagus*-dominated rainforest like that understood to have been present in southeastern Australia at that time. Instead, the Mulga Rock assemblages suggest a mosaic of vegetation communities, with *Nothofagus* likely part of the regional vegetation in the hinterland or upstream, *Myrtaceidites* spp. and *Proteacidites* spp. forming the local vegetation, and *Haloragacidites harrisii* (Casuarinaceae) present within both.

At Mulga Rock, the palynological trends reported here are limited to a cross section over the Princess and Ambassador deposits. Further research is required to determine how they extend to the Shogun and Emperor deposits in the northeast of the palaeovalley. As sampling was focused on the E2 lignite, many of the trends noted for the D interval also require further confirmation, as only a few samples were available for each. This study highlights the need for further palynological work on onshore Paleogene sediments in southwestern WA. The resolution of lithostratigraphic problems, most significantly the inconsistency in palynostratigraphic age assignments, is important for current and future mineral exploration. Correlation of work already completed in the Eucla and Bremer basins, and palaeodrainages, could allow for the construction of a WA specific

palynostratigraphic zonation. WA palaeovegetation is also the focus of ongoing work into the origins of sclerophylly and xeromorphy in Australia, with assemblages like those at Mulga Rock contributing significantly to the story.

References

Alley N. F. 1998. Cainozoic stratigraphy, palaeoenvironments and geological evolution of the Lake Eyre Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology* **144** (3), 239–263.

Alley N. F. and Beecroft A. 1993. Foraminiferal and palynological evidence from the Pidinga Formation and its bearing on Eocene sea level events and palaeochannel activity, eastern Eucla Basin, South Australia. *Memoirs of the Association of Australasian Palaeontologists* **15**, 375–393.

Alley N. F. and Benbow M. C. 1989. Late Eocene palynofloras from the Pidinga Formation, SADME Ooldea Range 6, eastern Eucla Basin. *Quarterly Geological Notes of the Geological Survey of South Australia* **111**, 2–12.

Alley N. F. and Broadbridge L. M. 1992. Middle Eocene palynofloras from the One Tree Hill area, St Vincent Basin, South Australia. *Alcheringa* **13**, 241–267.

Alley N. F., Krieg G. W. and Callen R. A. 1996. Early Tertiary Eyre Formation, lower Nelly Creek, southern Lake Eyre Basin, Australia: Palynological dating of macrofloras and silcrete, and palaeoclimatic interpretations. *Australian Journal of Earth Sciences* **43** (1), 71–84.

Al-Shawareb A. 2009. *Eocene palynology of a lignite section in the Muir-Unicup Catchment, Werillup Formation, south Western Australia*. Honours thesis, University of Western Australia, Perth, 98 pp. (unpublished).

Backhouse J. 1974. Stratigraphic palynology of the Watheroo Line boreholes, Perth Basin. *Geological Survey of Western Australia Annual Report* **1974**, 99–103.

Backhouse J. 1988. Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia. *Geological Survey of Western Australia Bulletin* **135** (1).

Backhouse J. 1989. Palynology of samples from the Kalgoorlie regional groundwater assessment boreholes KRM-1, KRN-1 and KRN-3. *Western Australia Geological Survey Palaeontology Report* **1989** (1).

Balme B. E. and Churchill, D. M. 1959. Tertiary sediments at Coolgardie, Western Australia. *Journal of the Royal Society of Western Australia* **42**, 37–43.

Banner F. T. 1989. The nature of *Globanomalina* Haque. *Journal of Foraminiferal Research* **19**, 171–179.

Barlow B. A. 1981. The Australian flora: its origin and evolution. *In: Flora of Australia Vol. 1*, pp. 25–75. Australian Government Publishing Service, Canberra, Australia.

Barton C. M., Bolger P. F., Holdgate G. R., Thompson B. R. and Webster R. L. 1995. Gippsland Basin. *In:* Ward C. R., Harrington H. J., Mallett C. W. and

Beeston J. W. (eds) *Geology of Australian Coal Basins, Geological Society of Australia Coal Geology Group Special Publication* **1,** 541–560.

Beard J. S. 1999. Evolution of the river systems of the south-west drainage division, Western Australia. *Journal of the Royal Society of Western Australia* **82**, 147–164.

Berggren W. A. 1977. Atlas of Palaeogene planktonic foraminifera, some species of the genera, *Subbotina, Planorotalites, Morozovella, Acarinina* and *Truncorotaloides*. *In:* Ramsay A. T. S. (ed.) *Oceanic micropaleontology,* p. 205–300. Academic Press, London, UK.

Blackburn D. T. 1981. Tertiary megafossil flora of Maslin Bay, South Australia: numerical taxonomic study of selected leaves. *Alcheringa* **5**, 9–28.

Blackburn D. T. 1985. Palaeobotany of the Yallourn and Morwell coal seams. *State Electricity Commission of Victoria, Melbourne Palaeobotanical Project – Unpublished Report 3*, 121 p.

Bint A. N. 1981. An Early Pliocene pollen assemblage from Lake Tay, southwestern Australia, and its phytogeographic implications. *Australian Journal of Botany* **29**, 277–291.

Bradshaw B.E., Rollet R., Totterdell J.M. and Borissova I. 2003. A revised structural framework for frontier basins on the southern and southwestern Australian continental margin. *Geoscience Australia Record 2003/03*, 94 p.

Burger D. 1989. Stratigraphy, palynology and palaeoenvironments of the Hooray Sandstone, eastern Eromanga Basin, Queensland and New South Wales. *Queensland Department of Mines Report* **3**, 24 p.

Burger D. 1996. Mesozoic palynomorphs from the North West Shelf, offshore Western Australia. *Palynology* **20**, 40–103.

Cardillo M. and Pratt R. 2013. Evolution of a hotspot genus: geographic variation in speciation and extinction rates in *Banksia* (Proteaceae). *BMC Evolutionary Biology* **13**, 155–166.

Carpenter R. J., Goodwin M. P., Hill R.S. and Kanold K. 2011. Silcrete plant fossils from Lightning Ridge, New South Wales: new evidence for climate change and monsoon elements in the Australian Cenozoic. *Australian Journal of Botany* **59**, 399–425.

Carpenter R. J., Jordan G. J. and Hill R.S. 1994. *Banksieaephyllum taylorii* (Proteaceae) from the Late Paleocene of New South Wales and its relevance to the origin of Australia's scleromorphic flora. *Australian Systematic Botany* **10**, 385–392.

Carpenter R. J. and Jordan G. J. 1997. Early Tertiary macrofossils of Proteaceae from Tasmania. *Australian Systematic Botany* **10**, 533–563.

Carpenter R. J., Goodwin M. P., Hill R.S. and Kanold K. 2011. Silcrete plant fossils from Lightning Ridge, New South Wales: new evidence for climate change and monsoon elements in the Australian Cenozoic. Australian Journal of Botany **59**, 399–425

Carpenter R. J., McLoughlin S., Hill R. S., McNamara K. J. and Jordan G. J. 2014. Early evidence of xeromorphy in angiosperms: stomatal encryption in a new Eocene species of Banksia (Proteaceae) from Western Australia. *American Journal of Botany* **101**, 1486–1497.

Carpenter R. J. and Pole M. 1995. Eocene Plant Fossils from the Lefroy and Cowan Paleodrainages, Western Australia. *Australian Systematic Botany* **8**, 1107–1154.

Chakravartula P. N. and Street G. 2000. Hydrogeological interpretation of airborne geophysical data Lake Muir Unicup Catchment, Western Australia. *Agraria Limited Report*.

Chapman F. 1921. A sketch of the geological history of Australian plants - the Cainozoic flora. *Victorian Naturalist* **37**, 115–119.

Chapman F. 1925a. Notes on the brown coal from Morwell, South Gippsland. *Geological Survey of Victoria Record* **4,** 485–487.

Chapman F. 1925b. On some seed-like bodies in the Morwell brown coal. *Geological Survey of Victoria Record* **4,** 487–489.

Chapman F. 1926a. New or little known fossils in the National Museum. *Proceedings of the Royal Society of Victoria* **38**, 183–191.

Chapman F. 1926b. The fossil *Eucalyptus* record. *Victorian Naturalist* **42**, 229–231.

Chapman F. and Crespin I. 1934. The palaeontology of the Plantagenet beds of Western Australia. *Journal of the Royal Society of Western Australia* **20,** 103–136.

Christophel D. C. 1980. Occurrence of *Casuarina* megafossils in the Tertiary of south-eastern Australia. *Australian Journal of Botany* **28,** 249–259.

Christophel D. C. 1981. Tertiary megafossil floras of Australia as indicators of floristic associations and palaeoclimate. *In*: A. Keast (ed.) *Ecological Biogeography of Australia*, pp. 377–390. Dr W. Junk, The Hague-Boston-London.

Christophel D. C. 1984. Early Tertiary Proteaceae: the first floral evidence for the Musgraveinae. *Australian Journal of Botany* **32**, 177–186.

Christophel D. C. 1989. Evolution of the Australian flora through the Tertiary. *Plant Systematics and Evolution* **162,** 63–78.

Christophel D. C. 1994. The early Tertiary macrofloras of continental Australia. *In*: Hill R S (ed.) *History of the Australian Vegetation: Cretaceous to Recent*, pp. 262–275. Cambridge University Press, Cambridge, UK.

Christophel D. C. and Blackburn D. T. 1978. The Tertiary megafossil flora of Maslin Bay, South Australia – a preliminary report. *Alcheringa* **2** (4), 311–319.

Christophel D .C. and Greenwood D. R. 1989. Changes in climate and vegetation in Australia during the Tertiary. *Review of Palaeobotany and Palynology* **58**, 95–109.

Christophel D. C., Scriven L. J. and Greenwood D. R. 1992. An Eocene megaflora from Nelly Creek, South Australia. *Transactions of the Royal Society of South Australia* **116,** 65–76.

Churchill D. M. 1962. The Tertiary and Quaternary vegetation and climate in relation to the living flora of south Western Australia. PhD thesis,), University of Western Australia, (unpublished).

Churchill D. M. 1973. The ecological significance of tropical mangroves in the Early Tertiary floras of southern Australia. *Geological Society of Australia Special Publication* **4,** 55–72.

Clarke J. D. A. 1993. Stratigraphy of the Lefroy and Cowan palaeodrainage channels, Western Australia. *Journal of the Royal Society of Western Australia* **76**, 13–23.

Clarke J. D. A. and Alley N. F. 1993. Petrologic data on the evolution of the Great Australia Bight. *In:* Findlay, R. H., Banks M. R., Veevers, L. J. and Unrug R.. (eds) *Gondwana 8 – Assembly, Evolution and Dispersal*, pp. 585-596.CRC Press, Rotterdam.

Clarke J. D. A., Gammon P. R., Hou B. and Gallagher S. J. 2003. Middle to late Eocene stratigraphic nomenclature and deposition in the Eucla Basin. *Australian Journal of Earth Sciences* **50**, 231–248

Cockbain A. E. 1968. The stratigraphy of the Plantagenet Group, Western Australia. *Geological Survey of Western Australia Annual Report* **1968,** 52–53.

Coleman P. J. 1952. Foraminiferal investigations in the Perth Basin, Western Australia. *Royal Society of Western Australia Journal* **36**, 31–43.

Commander P. 2003. The geomorphology of the Perth region, Western Australia. *Australian Geomechanics* **38** (3), 7–16.

Cookson I. C. 1945. Pollen content of Tertiary deposits. *Australian Journal of Science.* **7**, 149–150.

Cookson I. C. 1947. On fossil leaves (Olacaceae) and a new type of fossil pollen grain from Australian brown coal deposits. *Proceedings of the Linnaean Society of New South Wales.* **72**, 183–197.

Cookson I. C. 1950. Fossil pollen grains of Proteaceous type from Tertiary deposits in Australia. *Australian Journal of Biological Sciences* **3**, 166–177.

Cookson I. C. 1953a. Difference in microspore composition of some samples from a bore at Comaum, South Australia. *Australian Journal of Botany* **1** (3), 462–473.

Cookson I. C. 1953b. The identification of the sporomorph *Phyllocladidites* and *Dacrydium* and its distribution in southern Tertiary deposits. *Australian Journal of Botany* **1**, 64–70.

Cookson I. C. 1953c. On *Macrozamia hopeites* – an early Tertiary cycad from Australia. *Phytomorphology* **3**, 306–312.

Cookson I. C. 1954a. A palynological examination of No. 2 bore, Birregurra, Victoria. *Proceedings of the Royal Society of Victoria* **66**, 119–128.

Cookson I. C. 1954b. The occurrence of an older Tertiary microflora in Western Australia. *Geological Survey of Western Australia Memoir* **3**, 750–755.

Cookson I. C. 1954c. The Cainozoic occurrence of *Acacia* in Australia. *Australian Journal of Botany* **2**, 52–59.

Cookson I. C. 1959. Fossil pollen grains of *Nothofagus* from Australia. *Proceedings of the Royal Society of Victoria* **71,** 25–30.

Cookson I. C. and Duigan S. L. 1950. Fossil Banksieae from Yallourn, Victoria, with notes on the morphology and anatomy of living species. *Australian Journal of Biological Sciences* **3,** 133–165.

Cookson I. C. and Duigan S. L. 1951. Tertiary Araucariaceae from south eastern Australia, with notes on living species. *Australian Journal of Biological Sciences* **4,** 415–449.

Cookson I. C. and Pike K. M. 1953a. The Tertiary occurrence and distribution of *Podocarpus* (section *Dacrycarpus)* in Australia and Tasmania. *Australian Journal of Botany* **1,** 71–82.

Cookson I. C. and Pike K. M. 1953b. A contribution to the Tertiary occurrence of the genus *Dacrydium* in the Australian region. *Australian Journal of Botany* **1**, 474–484.

Cookson I. C. and Pike K. M. 1954a. Some dicotyledonous pollen types from Cainozoic deposits in the Australian region. *Australian Journal of Botany* **2**, 197–219.

Cookson I. C. and Pike K. M. 1954b. The fossil occurrence of *Phyllocladus* and two other podocarpaceous types in Australia. *Australian Journal of Botany* **2**, 60–68.

Davidson W. A. 1995. Hydrogeology and groundwater resources of the Perth region, Western Australia. *Geological Survey of Western Australia Bulletin* **142**, 257 p.

Dawson J. 1988. *Forest Vines to Snow Tussock: the Story of New Zealand's Plants.* Victoria University Press, Wellington, New Zealand, 264 pp.

Deane H. 1902. Preliminary note on the fossil flora of Pitfield, Mornington, Sentinel Rock (Otway coast), Berwick and Wonwron. *Records of the Geological Survey of Victoria* **1,** 13–32.

Deane H. 1904. Further notes on the Cainozoic flora of Sentinel rock, Otway Coast. *Records of the Geological Survey of Victoria* **1**, 212–215.

Deane H. 1923. Tertiary fossil fruits from deep lead, Foster, south Gippsland. *Records of the Geological Survey of Victoria* **4,** 489–492.

Deane H. 1925. Fossil leaves from the open cut, state brown coal mine, Morwell. *Records of the Geological Survey of Victoria* **4**, 492–498.

De Broekert P. P. and Sandiford M. 2005. Buried inset-valleys in the eastern Yilgarn Craton, Western Australia: geomorphology, age and allogenic control. *Journal of Geology* **113**, 471–193.

De Silva J. 2000. Pemberton-Irwin Inlet W. A. Sheet SI 50-10 and part of SI 50-14, Western Australia. *Water and Rivers Commission 1:250 000 Hydrogeological Series.*

De Silva J. 2003. Hydrogeology of the Pemberton-Irwin Inlet 1:250 000 sheet, Western Australia. *Water and Rivers Commission Hydrogeological Explanatory Notes Series,* Report **HM 8**.

Dettman M. E. and Clifford H. T. 2000. Monocotyledon fruits and seeds, and an associated palynoflora from Eocene-Oligocene sediments of coastal central Queensland, Australia. *Review of Palaeobotany and Palynology* **110** (3-4), 141–173.

Dodson J., Itzstein-Davey F., Milne L. and Morris A. 2002. Vegetation and Environmental History of Southern Western Australia. *In*: Gaynor A, Trinia M & Haibich A (eds) *Country: Visions of land and people in Western Australia,* pp. 147–167. Western Australian Museum, Perth, Australia.

Dodson J. and Macphail M. K. 2004. Palynological evidence for aridity events and vegetation change during the Middle Pliocene, a warm period in Southwestern Australia. *Global and Planetary Change* **41**, 285–307.

Douglas J. G. 1977. A new fossil plant assemblage from the Eastern View Coal measures. Geological Survey of Victoria unpublished report **1977/31**.

Douglas G. B., Butt C. M. and Gray D. J. 2011. Geology, geochemistry and mineralogy of the lignite-hosted Ambassador palaeochannel uranium and multi-element deposit, Gunbarrel Basin, Western Australia. *Miner Deposits* **46,** 761–787.

Dudgeon M. J. 1983. Eocene pollen of probable proteaceous affinity from the Yaamba Basin, central Queensland. Memoirs of the Association of Australasian Palaeontologists **1**, 339–362.

Duigan S. L. 1950. A catalogue of the Australian Tertiary flora. *Proceedings of the Royal Society of Victoria* **63**, 41–56.

Duigan S. L. 1966. The nature and relationships of the Tertiary brown coal flora of the Yallourn area in Victoria, Australia. *Palaeobotanist* **14,** 191–201.

Erdtman G. 1952. *Pollen morphology and plant taxonomy: Angiosperms*. Almqvist and Wiskell, Stockholm, Sweden. 539 p.

Erdtman G. 1960. The acetolysis method. A revised description. *Svensk Botanisk Tidskrift* **54**, 561–564.

Ettingshausen C. von. 1883. Beiträge zur Kenntniss der Tertiar-flora Australiens. Part 1. *Denkschriften der Österreichischen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Klasse* **47,** 101–148.

Ettingshausen C. von. 1886. Beiträge zur Kenntniss der Tertiar-flora Australiens. Part 2. *Denkschriften der Österreichischen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Klasse* **53,** 81–142.

Ettingshausen C. von. 1888. Contributions to the Tertiary flora of Australia. *Memoirs of the Geological Survey of New South Wales* **2**, 1–189.

Faegri K., Kaland P. E., Krzywinski K. 1989. *Textbook of Pollen Analysis.* John Wiley and Sons: Chichester, UK. 328 p.

Fewster M. 1999. *The Geology of the Narnoo Basin, Western Australia, and Origin of the Gold, Base-Metal, and Uranium Mineralisation During the Late Cenozoic.* Msc thesis, University of Western Australia, Perth.

Foster C. B. 1982. Spore-pollen assemblages of the Bowen Basin, Queensland (Australia): their relationship to the Permian/Triassic boundary. *Review of Palaeobotany and Palynology* **36** (1), 165–183.

Fulwood K. E. and Barwick R. E. 1990. Mulga Rock uranium deposits, Officer Basin. *In:* Hughes F. E. (ed.) *Geology of the Mineral Deposits of Australia and Papua New Guinea.* The Australasian Institute of Mining and Metallurgy, Monograph **14**, 1621–1623.

Germeraad J. H., Hopping C. A. and Muller J. 1968. Palynology of Tertiary sediments from tropical areas. *Review of Palaeobotany and Palynology* **6**, 189–348.

George A.S. 1999. Banksia. *In:* Wilson A. (ed.) *Flora of Australia, Vol. 17B, Proteaceae 3, Hakea to Dryandra*., pp. 175–250. ABRS, Canberra, ACT and CSIRO, Melbourne.

Gill E. D. 1949. Early Tertiary plant beds near Pascoe Vale, Melbourne, Victoria. *Victorian Naturalist* **66,** 69–73.

Gill E. D. and Baker A. A. 1950. Fossil plants in basalt at Maribyrnong, Victoria. *Victorian Naturalist* **67,** 123–129.

Gradstein F. M., Ogg J. G. and Smith A. G. 2005. *A Geologic Time Scale 2004.* Cambridge University Press, Cambridge, UK. 589 p.

Greenwood D. R. 1987. Early Tertiary Podocarpaceae: megafossils from the Eocene Anglesea location, Victoria. *Australian Journal of Botany* **35,** 111–133.

Greenwood D. R. 1994. Palaeobotanical evidence for Tertiary climates. *In*: Hill R. S. (ed.), *History of the Australian Vegetation: Cretaceous to Recent*, pp. 44–59. Cambridge University Press, Cambridge, UK.

Greenwood D. R., Haines P. W. and Steart D.W. 2001. New species of *Banksieaeformis* and a *Banksia* 'cone' (Proteaceae) from the Tertiary of central Australia. *Australian Systematic Botany* **14**, 871–890.

Greenwood D. R., Vadala A. J. and Banks M.A. 2000. Climate change and vegetation responses during the Paleocene and Eocene in southeastern Australia. *GFF* **122**, 65–66.

Greenwood D. R. and Wing S. L. 1995. Eocene continental climates and latitudinal temperature gradients. *Geology* **23,** 1044–1048.

Haig D. W., Griffin B. J. and Ujetz B. F. 1993. Redescription of type specimens of *Globorotalia chapmani* Parr from the upper Paleocene, Western Australia. *Journal of Foraminiferal Research* **23** (4), 275–280.

Harris W. K. 1965. Basal Tertiary microfloras from the Princetown area, Victoria, Australia. *Palaeontographica Abteilung B: Palaeophytologie* **115**, 75–106.

Harris W. K. 1971. Tertiary stratigraphic palynology, Otway Basin. *In*: Wopfner H. and Douglas J. G. (eds) *The Otway Basin of Southeastern Australia, Special Bulletin of the Geological Surveys of South Australia and Victoria*, pp. 67–87.

Harris W. K. 1972. New form species of pollen from southern Australian early Tertiary sediments. *Transactions of the Royal Society of South Australia* **96**, 53–65.

Harris W. K. 1985. Middle to Late Eocene depositional cycles and dinoflagellate zones in southern Australia. *Special Publications of the South Australian Department of Mines and Energy* **5**, 133–144.

Harris W. K. 1989. Palynology of seven samples from the Norseman area. *Kambalda Nickel Operations Geological Exploration File* **9/G/6L**.

Harris W. K. and Cookson I. C. 1965. The stratigraphy of the Comaum No. 2 bore – A reinterpretation. *Australian Journal of Science* **28,** 25–26.

Haskell T. R. and Wilson G. J. 1975. Palynology of Sites 280-284, DSDP Leg 29, off southeastern Australia and western New Zealand. *In:* Kennett J. P. and Houtz R. E. (eds) *Initial Reports of the Deep Sea Drilling Project* **29**, 723–741.

Hill R. S. 1978. Two new species of Bowenia Hook, ex Hook.f., from the Eocene of eastern Australia. *Australian Journal of Botany* **26**, 837–846.

Hill R. S. 1980. Three new Eocene cycads from eastern Australia. *Australian Journal of Botany* **28**, 105–122.

Hill R. S. 1987. Discovery of *Nothofagus* fruits corresponding to an important Tertiary pollen type. *Nature* **327**, 56–58.

Hill R. S. 1988. Australian Tertiary angiosperm and gymnosperm leaf remains: an updated catalogue. *Alcheringa* **12**, 207–219.

Hill R. S. 1990. Evolution of the modern high latitude southern hemisphere flora: evidence from the Australian macrofossil record. *In*: Douglas J G & Christophel DC (eds) *Proceedings of the 3rd IOP Conference,* 31–42.

Hill R. S. 1992. Australian vegetation during the Tertiary: macrofossil evidence. *Beagle* **9**, 1–10.

Hill R. S. 1994. *The History of the Australian Vegetation: Cretaceous to Recent.* University Press, Cambridge, UK. 433 p.

Hill R. S. 2004. Origins of the southeastern Australian vegetation. *Philosophical Transactions of the Royal Society of London* B **359**, 1537–1549.

Hill R. S. and Christophel D. C. 1988. Tertiary leaves of the tribe Banksieae (Proteaceae) from southeastern Australia. *Botanical Journal of the Linnean Society* **97**, 205–227.

Hill R. S. and Macphail M.K. 1983. Reconstruction of the Oligocene vegetation at Pioneer, northeast Tasmania. *Alcheringa* **7**, 281–299.

Hill R. S. and Merrifield H. E. 1993. An early Tertiary macroflora from West Dale, southwestern Australia. *Alcheringa* **17**, 285–326.

Hocking R. M. and Cockbain A. E. 1990. Regolith. *In: Geology and Mineral Resources of Western Australia, Western Australian Geological Survey Memoir* **3**, 591–602.

Hopper S. D. and Gioia P. 2004 The Southwest Australian Floristic Region: evolution and conservation of a global hotspot of biodiversity. *Annual Review of Ecology Evolution and Systematics* **35**, 623–650.

Hos D. 1975. Preliminary investigations of the palynology of the Upper Eocene Werillup Formation, Western Australia. *Journal of the Royal Society of Western Australia* **58**, 1–14.

Hou B., Frakes L. A. and Alley N. F. 2001. Development of geoscientific models for exploration in Tertiary palaeochannels draining the northwest Gawler Craton, SA. *Department of Primary Industries and Resources South Australia Report Book* **2001/021**. 133 p.

Hou B., Alley N. F., Frakes L. A., Stoian L. and Cowley W. M. 2006. Eocene stratigraphic succession in the Eucla Basin of South Australia and correlation to major regional sea level events. *Sedimentary Geology* **183**, 297–319.

Hou B., Frakes L. A., Sandiford M., Worrall L., Keeling J. and Alley N. F. 2008. Cenozoic Eucla Basin and associated palaeovalleys, southern Australia — Climatic and tectonic influences on landscape evolution, sedimentation and heavy mineral accumulation. *Sedimentary Geology* **203**, 112–130.

Inwood N. 2009. Mulga Rocks Deposits January 2009 Resource Estimate. *Coffey Mining Pty. Ltd Report.* 52 p.

Islam M. A. 1983. Palynological report on samples from the western Eucla Basin. *ECL Australia Pty Ltd Report* **R12/83/1**, 7 p.

Itzstein-Davey F. 2004. A spatial and temporal Eocene palaeoenvironmental study, focusing on the Proteaceae family, from Kambalda, Western Australia. *Review of Palaeobotany and Palynology* **131** (3), 159–180.

Johnson L. A. S. and Briggs B.G. 1975. On the Proteaceae: the evolution and classification of a southern family. *Botanical Journal of the Linnean Society* **70** (2), 83–182.

Jones B. G. 1990. Cretaceous and Tertiary sedimentation on the western margin of Eucla Basin. *Australian Journal of Earth Sciences* **37** (3), 317–329.

Jordan G. J. and Hill R. S. 1991. Two new *Banksia* species from Pleistocene sediments in western Tasmania. *Australian Systematic Botany* **4**, 199–511.

Kemp E. M. 1978. Tertiary climatic evolution and vegetation history in the south-east Indian Ocean region. *Palaeogeography, Palaeoclimatology, Palaeoecology* **24**, 169–208.

Kemp E. M. 1981. Tertiary palaeogeography and evolution of Australian climate. *In*: A Keast (ed.), *Ecological Biogeography of Australia*, pp. 31–50. Dr W. Junk, The Hague-Boston-London.

Kemp E. M. and Harris W. K. 1977. *The palynology of early Tertiary sediments Ninetyeast Ridge Indian Ocean.* Palaeontological Association.

Kern A. M. and Commander D. P. 1993. Cainozoic stratigraphy in the Roe Palaeodrainage of the Kalgoorlie Region, Western Australia. *Geological Survey of Western Australia Report* **34**, 85–95.

Kershaw A. P. A pollen diagram from Lake Euramoo, north-east Queensland, Australia. *New Phytologist* **69**, 785–805.

Kremp G. O. W. 1965. *Morphologic Encyclopedia of Palynology*, 2nd edn University of Arizona Press, Tucson, AZ, USA)\. 263 p.

Lange R. T. 1978. Some Eocene leaf fragments comparable with Proteaceae. *Journal of the Royal Society of Western Australia* **60**, 107–114.

Lange R. T. 1982. Australian Tertiary vegetation: evidence and interpretation. *In*: J.M.B. Smith (ed.) *A History of Australasian Vegetation*, pp. 44–89. McGraw-Hill Book Company, Sydney, Australia.

Li Q., James N. P. and McGowran B. 2003. Middle and Late Eocene Great Australian Bight lithostratigraphy and stepwise evolution of the southern Australian continental margin. *Australian Journal of Earth Sciences* **50**, 113–128.

Lowry D. C. 1968. Tertiary stratigraphic units in the Eucla Basin in Western Australia. *Annual Report of the Geological Survey of Western Australia* **1967**, 40–44.

Lowry D. C. 1970. Geology of the Western Australian part of the Eucla Basin. *Geological Survey of Western Australia Bulletin* **122.**

Luly J., Sluiter I. R. and Kershaw A. P. 1980. Pollen studies of Tertiary brown coals: preliminary analyses of lithotypes within the Latrobe Valley, Victoria. *Monash Publications in Geography* **23**, 78pp.

Mack C. L. 2011. *Tertiary palynology of the southern Officer Basin, Western Australia.* Honours thesis, Curtin University, Perth, 109 pp. (unpublished).

Mack C. L. and Milne L.A. 2015 Eocene palynology of the Mulga Rocks deposits, southern Gunbarrel Basin, Western Australia. *Alcheringa* **39** (4), 444–458.

Macphail M. K. 1999. Palynostratigraphy of the Murray Basin, inland southeastern Australia. *Palynology* **23**, 197–240.

Macphail M. K. 2007. Australian palaeoclimates: Cretaceous to Tertiary - A review of palaeobotanical and related evidence to the year 2000. *CRCLEME Open File Report* **151,** 266 p.

Macphail M. K., Alley N. F., Truswell E. M. and Sluiter I. R. K. 1994. Early Tertiary vegetation: evidence from spores and pollen. *In*: R S Hill (ed.), *History of the Australian Vegetation: Cretaceous to Recent*, pp. 189–261. Cambridge University Press, Cambridge, UK.

Macphail M. K. and Truswell E. M. 1989. Palynostratigraphy of the central west Murray Basin. *BMR Journal of Australian Geology and Geophysics* **11**, 303–331.

Macphail M. K. and Truswell E. M. 1993. Palynostratigraphy of the Bookpurnong Beds and related Late Miocene-Early Pliocene facies in the central west Murray Basin, part 2: spores and pollen. *AGSO Journal of Australian Geology and Geophysics* **14** (4), 383–409.

Macphail M. K. and Cantrill D. 2006. Age and implications of the Forest Bed, Falkland Islands, southwest Atlantic Ocean: evidence from fossil pollen and spores. *Palaeogeography, Palaeoclimatology, Palaeoecology* **240**, 602–629.

Magee J. W. 2009. Palaeovalley groundwater resources in arid and semi-arid Australia – A literature review. *Geoscience Australia Record* **2009/003,** 249 p.

Martin A. R. H. 1982. Proteaceae and the early differentiation of the central Australian flora. *In:* W. R. Barker and P. J. M Greenslade (eds) *Evolution of the Flora and Fauna of Arid Australia*. pp. 77–83. Peacock Publications, South Australia, Australia.

Martin H. A. 1973a. The palynology of some Tertiary and Pleistocene deposits, Lachlan River Valley, New South Wales. *Australian Journal of Botany Supplementary Series* **6**, 1–57.

Martin H. A. 1973b. Upper Tertiary palynology in southern New South Wales. *Special Publications of the Geological Society of Australia* **4**, 35–54.

Martin H. A. 1977. Tertiary Stratigraphic palynology of the Murray Basin in New South Wales. I. The Hay-Balranald-Wakool Districts. *Journal and Proceedings of the Royal Society of New South Wales* **110**, 41–47.

Martin H. A. 1978. Evolution of the Australian flora and vegetation through the Tertiary: evidence from pollen. *Alcheringa* **2**, 181–202.

Martin H. A. 1979. Stratigraphic palynology of the Mooki Valley. *Journal and Proceedings of the Royal Society of New South Wales* **112**, 71–78.

Martin H. A. 1980. Stratigraphic palynology from shallow bores in the Namoi River and Gwydir River valleys, north-central New South Wales. *Journal and Proceedings of the Royal Society of New South Wales* **113**, 81–87l

Martin H. A. 1981. The Tertiary flora. *In*: A. Keast (ed.) *Ecological Biogeography of Australia*, pp. 391–406. Dr W. Junk, The Hague-Boston-London.

Martin H. A. 1984a. The use of quantitative relationships and palaeoecology in stratigraphic palynology of the Murray Basin in New South Wales. *Alcheringa* **8**, 253-272.

Martin H. A. 1984b. The stratigraphic palynology of the Murray Basin in New South Wales. II. The Murrumbidgee area. *Journal and Proceedings of the Royal Society of New South Wales* **117**, 35–44.

Martin H. A. 1984c. Stratigraphic palynology of the Murray Basin in New South Wales III. The Lachlan area. *Journal and Proceedings of the Royal Society of New South Wales* **117**, 45–51.

Martin H. A. 1986. Cainozoic history of the vegetation and climate of the Lachlan River Region, New South Wales. *Proceedings of the Linnaean Society of New South Wales*, **109** (4), 213–257.

Martin H. A. 1988. Stratigraphic palynology of the Lake Menindee region, New South Wales. *Journal and Proceedings of the Royal Society of New South Wales* **121**, 1–9.

Martin H. A. 1990. Tertiary climate and phytogeography in southeastern Australia. *Review of Palaeobotany and Palynology* **65**, 47–55.

Martin H. A. 1991. Dinoflagellate and spore pollen biostratigraphy of the S.A.D.M.E. MC63 bore, western Murray Basin. *Alcheringa* **15**, 107–144.

Martin H. A. 1993a. Middle Tertiary dinoflagellate and spore-pollen biostratigraphy and palaeoecology of the Mallee Cliffs bore, central Murray Basin. *Alcheringa* **17,** 91-124.

Martin H. A. 1993b. The palaeovegetation of the Murray Basin, Late Eocene to mid-Miocene. *Australian Systematic Botany* **6**, 491–531.

Martin H. A. 1994. Australian Tertiary phytogeography: evidence from palynology. *In*: Hill R.S (ed.) *History of the Australian Vegetation: Cretaceous to Recent*, pp. 104–142. Cambridge University Press, Cambridge, UK.

Mast A. R. and Thiele K. 2007. The transfer of *Dryandra* R. Br. to *Banksia* L.f. (Proteaceae). *Australian Systematic Botany* **20**, 63–71.

McCoy F. 1876. Prodromus of the palaeontology of Victoria. *Geological Survey of Victoria Special Publication,* 29–32.

McGowran B. 1964. Foraminiferal evidence for the Paleocene age of the Kings Park Shale (Perth Basin, Western Australia). *Journal of the Royal Society of Western Australia* **79** (1), 81–86.

McGowran B. 1968. Reclassification of early Tertiary *Globorotalia*. *Micropaleontology* **14**, 179–198.

McGowran B. 1989. The later Eocene transgressions in southern Australia. *Alcheringa* **13** (1), 45–68.

McIntyre D. J. 1968. Further new pollen species from New Zealand Tertiary and uppermost Cretaceous deposits. *New Zealand Journal of Botany* **6** (2) 177–204.

McLoughlin S. and Guppy L. 1993. Western Australia's Tertiary Floras. *The Fossil Collector* **40**, 13–22.

McLoughlin S. and Hill R. S., 1996. The succession of Western Australian Phanerozoic floras. *In*: Hopper S. D., Chappill J. A., Harvey M. S. and George A. S. (eds) *Gondwanan Heritage: Past, Present and Future of the Western Australian Biota Proceedings of the Conference on Systematics, Evolution and Conservation of the Western Australian Biota, Perth, 1993*, pp. 61–80. Surrey Beatty, Sydney, Australia.

McLoughlin S. and McNamara K. 2001. *Ancient Floras of Western Australia*. Western Australian Museum, Perth. 42 pp.

McNamara K. J. 1992. *A guide to the fossils of the Albany region.* Department of Earth and Planetary Science, Western Australian Museum, Perth, Australia. 12 p.

McNamara K. J. and Scott J. K. 1983. A new species of *Banksia* (Proteaceae) from the Eocene Merlinleigh Sandstone of the Kennedy Range, Western Australia. *Alcheringa* **7**, 185–193.

McWhae J. R. H., Playford P. E., Lindner A. W., Glenister B. F. and Balme B. E. 1958. The stratigraphy of Western Australia. *Journal of the Geological Society of Australia* **4** (2), 1–155.

Memon H. R. 1976. *A comparative scanning electron microscopic study of pollen of modern Proteaceae and fossil forms from Australia and Northern Hemisphere attributed to the family*. PhD thesis, Sydney University. (unpublished).

Middleton M. F. 1990. Tectonic history of the southern continental margin of Western Australia. *Geological Survey of Western Australia Record* **1990/8**.

Mildenhall D. C. 1980. New Zealand Late Cretaceous and Cenozoic plant biogeography: a contribution. *Palaeogeography, Palaeoclimatology and Palaeoecology* **31**, 197–233.

Mildenhall D. C. 1994. Palynological reconnaissance of Early Cretaceous to Holocene sediments, Chatham Islands, New Zealand. *New Zealand Geological Survey Paleontological Bulletin* **57**. 206 p.

Mildenhall D. C. and Pocknall D. T. 1984. Late Oligocene-Early Miocene spores and pollen from Southland, New Zealand. *New Zealand Geological Survey Paleontological Bulletin* **51**, 66 p.

Mildenhall D. C., Pocknall D. T. and Gregory J. G. 1989. Miocene-Pleistocene spores and pollen from Central Otago, South Island, New Zealand. *New Zealand Geology Survey Paleontological Bulletin* **59**, 128 p.

Milne L. A. 1988. Palynology of a late Eocene lignitic sequence from the western margin of the Eucla Basin, Western Australia. *Memoirs of the Association of Australasian Palaeontologists* **5**, 285–310.

Milne L. A. 1994. Relationship between Propylipollis annularis (Tertiary dispersed pollen) and extant Xylomelum (Proteaceae). *In*: Kurmann M. H. and Doyle J. A. (eds) *Ultrastructure of Fossil Spores and Pollen*, pp. 193–213. Royal Botanic Gardens, Kew, UK.

Milne L. A. 1997. *Palynology of selected extant Proteaceae and Eocene palynofloras of Western Australia*. PhD thesis, The University of Queensland, Queensland. 191p. (unpublished).

Milne L. A. 1998. Tertiary Palynology: Beaupreaidites and New Conospermeae (Proteoideae) Affiliates. *Australian Systematic Botany* **11**, 553–603.

Milne L. A. 2003. Palynological analysis of three samples from borehole 14. *Water and Rivers Commission Report* **ME/BP 61**.

Milne L. A. and Martin A. R. H. 1998. Conospermeae pollen morphology and its phylogenetic implications. *Australian Systematic Botany* **11**, 503–552.

Moore P. D., Webb J. A. and Collinson M. 1991. *Pollen Analysis*. Blackwell, London, UK. p. 216

Morely B. D. and Toelken H. R. 1983. *Flowering Plants in Australia.* Rigby, Willoughby, NSW, Australia. 416 p.

Mueller F. von. 1874. *Observations on new vegetable fossils of the auriferous drifts.Vol. 1.* Geological Survey of Victoria, Melbourne, Australia. 31 p.

Mueller F. von. 1883. *Observations on new vegetable fossils of the auriferous drifts.* Vol. 2. Geological Survey of Victoria, Melbourne, Australia. 23 p.

Nichols G. 2009. *Sedimentology and Stratigraphy*. 2nd ed. John Wiley & Sons, United Kingdom.

Parker F. 1988. Palynology of samples from Lake Lefroy. *Kambalda Nickel Operations Geology Department Technical Report* **2922**.

Partridge A. D. 1976. The geological expression of eustacy in the early Tertiary of the Gippsland Basin. *APPEA Journal* **16**, 73–79.

Partridge A. D. 2006. Late Cretaceous – Cenozoic Palynology Zonations Gippsland Basin. *In*: E. Montall (coord.) *Australian Mesozoic and Cenozoic Palynology Zonations.* Geoscience Australia Record **2006/23**.

Paterson H. T. 1934. Notes on some Tertiary leaves from Pascoe Vale. *Proceedings of the Royal Society of Victoria* **46**, 264–268.

Paterson H. T. 1935. Notes on plant remains from Narracan and Darlimurla, south Gippsland. *Proceedings of the Royal Society of Victoria* **48**, 67–74.

Patton R. T. 1928. Fossil plants of the Stony Creek basin. *Proceedings of the Royal Society of Victoria (new series)* **40**, 88–90.

Patton R. T. 1936. A fossil *Casuarina. Proceedings of the Royal Society of Victoria* **49**, 36–39.

Patton R. T. 1958. Fossil wood from Victorian brown coal. *Proceedings of the Royal Society of Victoria.* **70,** 129–143

Paull R. and Hill R. S. 2010. *Report on Leaf Fossils Removed from Drill-Hole NND5004, Mulga Rocks Uranium Deposit, Western Australia*. Report, University of Adelaide, Adelaide, 21 pp.

Phipps D. and Playford G. 1984. Laboratory techniques for extraction of palynomorphs from sediments. *Papers of the Department of Geology, the University of Queensland* **11** (1), 1–23

Pike K. M. 1949. Pollen investigations on the ligneous beds – Lake MacDonnell bore. *Mining Review of Adelaide* **88,** 270–272.

Pike K. M. 1950. Pollen investigations on the ligneous beds – Pidinga bore. *Mining Review of Adelaide* **90**, 63–65.

Pike K. M. 1953. Fossil fruiting cones of *Casuarina* and *Banksia* from Tertiary deposits in Victoria. *Proceedings of the Royal Society of Victoria* **65**, 1–8.

Playford P. E., Cockbain A. E. and Low G. H. 1976. Geology of the Perth Basin Western Australia. *Geological Society of Western Australia Bulletin* **124.**

Playford P. E, Cope R. N., Cockbain A. E, Low G. H. and Lowry D. C. 1975. Phanerozoic. *In:* Geology of Western Australia. *Western Australian Geological Survey Memoir* **2**, 223–433.

Pocknall D. T. 1982. Palynology of Late Oligocene Pomahaka Estuarine Bed sediments, Waikoikoi, Southland, New Zealand. *New Zealand Journal of Botany* **20**, 263–287.

Pocknall D. T. and Crosbie Y. M. Pollen morphology of Beauprea (Proteaceae): modern and fossil. *Review of Palaeobotany and Palynology* **53**, 305–327.

Punt W., Hoen P. P., Blackmore S., Nilsson S. and Le Thomas A. 2007. Glossary of pollen and spore terminology. *Review of Palaeobotany and Palynology* **143**, 1–81.

Quilty P. G. 1974. Tertiary stratigraphy of Western Australia. *Journal of the Geological Survey of Western Australia* **21** (3), 301–318.

Raine J. I., Mildenhall D. C. and Kennedy E. M. 2011. New Zealand fossil spores and pollen: an illustrated catalogue. *GNS Science Miscellaneous Series* **4**.

Redaway W. 1858. On the gold-diggings at Creswick Creek and Ballarat. *Quarterly Journal of the Geological Society of London* **14**, 540–541.

Rowett A. I. and Christophel D. C. 1990. The dispersed cuticle profile of the Eocene Anglesea clay lenses. *In*: Douglas J. G. and Christophel D. C. (eds) *Proceedings of the Third IOP Conference*, pp. 137–147. A-Z Press, Melbourne, Australia.

Rozefelds A. C. 1988. Insect leaf mines from the Eocene Anglesea locality, Victoria, Australia. *Alcheringa* **12,** 1–6.

Rozefelds A. C., Christophel D. and Alley N. F. 1992. Tertiary occurrence of the fern *Lygodium* (Schizaeaceae) in Australia and New Zealand. *Memoirs of the Queensland Museum* **32,** 203–222.

Scriven L. J., McLoughlin S and Hill R. S. 1995. *Nothofagus plicata* (Nothofagaceae), a new deciduous Eocene macrofossil species, from southern continental Australia. *Review of Palaeobotany and Palynology* **86** (3–4), 199–209.

Sedgley M., Sierp M., Wallwork M. A., Fuss A. M. and Thiele K. 1993. Pollen presenter and pollen morphology of *Banksia* L.f. (Proteaceae). *Australian Journal of Botany* **41** (5), 439–464.

Sluiter I. R. K. 1991. Early Tertiary vegetation and climates, Lake Eyre region, northeastern South Australia. *In*: The Cainozoic in Australia: a re-appraisal of the evidence. Geological Society of Australia, Sydney, 99–113.

Smith M. G. 2003. Groundwater and sediment sampling for the proposed Muir-Unicup drilling investigation, Western Australia. *Water and Rivers Commission Hydrogeological Record Series* Report HG 1.

Smith M. G. and Hearn R. W. 2006. The Lake Muir-Unicup Catchment, clarifying the geology. *Regolith 2006 – Consolidation and Dispersion of Ideas*, 322–325.

Smyth R. B. 1873. Report of progress. *Geological Survey of Victoria* **1**, 30.

Smyth R. B. 1875. Report of progress. *Geological Survey of Victoria* **2**, 28.

Stainforth, R. M., Lamb J. L. Luterbacher H., Beard J. H. and Jeffords R. M. 1975. Cenozoic planktonic foraminiferal zonation and characteristics of index forms. *The University of Kansas Paleontological Contributions* **62**, 425 p.

Stover L. E. and Evans P. R. 1973. Upper Cretaceous-Eocene spore-pollen zonation, offshore Gippsland Basin, Australia. *Special Publications of the Geological Society of Australia* **4**, 55–72.

Stover L. E. and Partridge, A. D. 1973. Tertiary and Late Cretaceous spores and pollen from the Gippsland Basin, southeastern Australia. *Proceedings of the Royal Society of Victoria* **85**, 237–286.

Stover L. E. and Partridge A. D. 1982. Eocene spore-pollen from the Werillup Formation, Western Australia. *Palynology* **6**, 69–95.

Taylor G., Truswell E. M., McQueen K. G. and Brown M. C. 1990. Early Tertiary palaeogeography, landform evolution and palaeoclimates of the Southern Monaro, N.S.W. Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology* **78**, 109–134.

Thiele K. R. and Mast A. R. 2007. Further recombinations of *Dryandra* into *Banksia*. *Nuytsia* **16** (2), 475.

Thornhill A. H. and Macphail M. 2012. Fossil myrtaceous pollen as evidence for the evolutionary history of Myrtaceae: a review of fossil *Myrtaceidites* species. *Review of Palaeobotany and Palynology* **176**, 1–23.

Toumarkine M. and Luterbacher H. 1985. Paleocene and Eocene planktic foraminifera. *In:* Bolli H. M., Saunders J. B. and Perch-Nielsen K. (eds) *Plankton stratigraphy*, pp. 87–154 Cambridge University Press, Cambridge, UK.

Truswell E. M. 1993. Vegetation changes in the Australian Tertiary in response to climatic and phytogeographic forcing factors. *Australian Systematic Botany* **6**, 533–557.

Truswell E. M. and Owen J. A. 1988. Eocene pollen from Bungonia, New South Wales. *Memoir of the Association of Australasian Palaeontologists* **5**, 259–284.

Truswell E. M., Sluiter I. R.K. and Harris W. K. 1985. Palynology of the Oligocene-Miocene sequence in the Oakvale-1 corehole, western Murray Basin, South Australia. *Journal of Australian Geology and Geophysics* **9**, 267–295.

Utescher T. and Mosbrugger U. 2007. Eocene vegetation patterns reconstructed from plant diversity – a global perspective. *Palaeogeography, Palaeoclimatology, Palaeoecology* **247,** 243–271.

Vadala A. J. and Drinnan A. N. 1998. Elaborating the fossil history of Banksiinae: a new species of *Banksieaephyllum* (Proteaceae) from the late Paleocene of New South Wales. *Australian Systematic Botany* **11**, 439–463.

Van de Graaff W. J. E., Crowe R. W. A., Bunting J.A. and Jackson M. J. 1977. Relict early Cenozoic drainages in Arid Western Australia. *Zeitschrift für Geomorphologie* **21**, 379–400.

Veblen T. T., Hill R. S. and Read, J. 1996. *The Ecology and Biogeography of Nothofagus forests.* 403 p. Yale University Press.

Veevers I. J. 2000. *Billion-year history of Australian and neighbours in Gondwanaland*. 400 p. GEMOC Press, Sydney.

Wagstaff B. E. and McEwen M. J. 1989 Palynological dating of Lower Cretaceous vertebrate localities, Victoria, Australia. *National Geographic Research* **5** (10), 54–63

Waterhouse J. D., Commander D. P., Prangley, C. and Backhouse J. 1994. Newly recognized Eocene sediments in the Beaufort River Palaeochannel. *GSWA 1993-94 Review*, 82–86.

Wilde S. A. and Backhouse J. 1977. Fossiliferous Tertiary deposits on the Darling Plateau, Western Australia. *Geological Survey of Western Australia Annual Report* **1976**, 49–52.

Wrigley J. W., Fagg M. 1989. *Banksias, Waratahs & Grevilleas - and all other plants in the Australian Proteaceae family*. William Collins Publishers, Sydney, Australia. 584p.

Wrońska-Pilarek D., Jagodziński A. M., Bocianowski J. and Janyszek M. 2015. The optimal sample size in pollen morphological studies using the example of *Rosa canina* L. (Rosaceae). *Palynology* **39**, 56–75.

Yew E. 2012. *Palynology of Eocene sediments from the Muir-Unicup Catchment, south Western Australia*. Honours thesis, Curtin University, Perth (unpublished).

APPENDIX 1. Sample depths, lithology and stratigraphic intervals for studied samples

Drillhole	Sample Depth (m)	Lithology
NNA-5605	41-42	Mid brown lignitic clay, minor coarse sand
NNA-5605	46-47	Dark brown-black lignite, minor pale yellow carbonate fragments
NNA-5605	50-51	Dark brown lignitic clay, minor sand
NNA-5605	54-55	Brown lignite, orange calcareous fragments
NNA-5605	56-57	Black clayey lignite, orange calcareous fragments
NNA-5605	60-61	Dark brown-black lignite
NNA-5605	62-63	Light grey mudstone
NNA-5605	64-65	Blue-grey mudstone
NNA-5738	49-50	Dark brown to black clayey lignite, minor very fine sand
NNA-5738	52-53	Black silt, unconsolidated
NNA-5738	59-60	Dark brown claystone, minor fine sand, white calcareous fragments
NNA-5738	61-62	Brown/black lignite
NNA-5738	64-65	Black, carbonaceous, silty sandstone
NNA-5738	70-71	Black lignite
NNA-5738	72-73	Light grey brown clay, soft, consolidated
NNA-5738	91-92	Light brown claystone, very fine sand
NNA-5738	98-99	Basement metasediments
NND-5077	51.1	Mid-dark brown claystone, wood fragments
NND-5077	51.3	Dark brown claystone leaf and wood fragments and bark
NND-5077	51.5	Mid-dark brown claystone wood fragments
NND-5077	51.7	Mid-dark brown claystone black wood fragments
NND-5077	51.9	Dark brown lignitic claystone, black wood fragments
NND-5077	52.1	Dark brown claystone, black wood fragments
NND-5077	52.3	Dark brown claystone, black wood fragments
NND-5077	52.5	Dark brown-black claystone, wood fragments
NND-5077	52.7	Mid brown siltstone, med-coarse angular sand fraction
NND-5077	53.7	Black, carbonaceous, very fine to medium sand
NND-5077	53.9	Dark grey to black, very fine to very coarse, carbonaceous sand
NND-5028	37.5	Mid brown shale, laminated, fine dark brown layers
NND-5028	39.1	Dark brown claystone, wood fragments, blocky fracture
NND-5028	39.6	Mid brown claystone, wood fragments, blocky fracture
NND-5028	40.5	Mid brown claystone, wood fragments, blocky fracture
NND-5028	41.5	Mid brown claystone, wood fragments, blocky fracture
NND-5028	42.2	Mid-dark brown claystone, wood fragments, blocky fracture
NND-5028	43	Dark brown claystone
NND-5028	43.6	Mid-dark brown claystone, roots
NND-5028	44.1	Mid-dark brown claystone, large chunks of wood
NND-5028	45	Greyish-mid brown siltstone
NND-5028	45.8	Mid brown (slightly greyish) siltstone with wood fragments
NND-5028	46.3	Mid brown claystone, wood fragments
NND-5028	48.2	Mid brown claystone
NND-5028	48.4	Mid brown sandy siltstone, coarse angular sand
NND-5028	58.3	Dark grey-brown silty sand
NND-5028	58.5	Dark grey-brown silty sand

Drillhole	Sample Depth	Lithology
NNA-5507	47-48	Black silt, unconsolidated
NNA-5507	52-53	Black carbonaceous silty sandstone, fine to medium grey quartz
NNA-5507	54-55	Light brown siltstone, fine to medium sand, few coarse grains
NNA-5507	59-60	Mid brown lignite, sulphates?, fine to medium sand
NNA-5507	71-72	Brown, coarse to medium grained sandstone, silt matrix
NNA-5507	73-74	Brown claystone, calcareous fragments and fine sand
NND-5030	35.9	Dark brown-black siltstone
NND-5030	37.2	Mid brown siltstone
NND-5030	40.4	Dark brown siltstone
NND-5030	41.6	Dark brown siltstone
NND-5030	42.2	Mid to dark brown siltstone
NND-5030	43	Dark grey silty sand
NND-5030	44.6	Light-mid brown siltstone, wood fragments
NND-5030	46.2	Light-mid brown siltstone, minor coarse sand, wood fragments
NND-5030	51.3	Mid-dark brown siltstone, minor medium sand, wood, leaves
NND-5030	58.2	Light-dark grey siltstone
NND-5030	61.8	Silver grey siltstone, interlaminated with dark grey siltstone
CD-1-779	37.9-38	Dark brown to black lignitic clay
CD-1-779	39.9-40	Mid brown lignitic clay, wood fragments
CD-1-779	44.9-45	Light brown-grey claystone, worm burrows
CD-1-779	49.9-50	Dark brown coarse sand, poorly sorted
CD-1-779	65.5-65.6	Silty sand
CD-1-779	71.2-71.3	Brown to black to grey interlayered clay and sandy clay
CD-1-779	80.9-81	Grey to brown claystone interlayered with fine-med sand
NNA-5510	43-44	Dark brown-black silt, unconsolidated with minor fragments
NNA-5510	44-45	Black silt, unconsolidated, white-yellow calcareous fragments
NNA-5510	45-46	Black silt, unconsolidated, rounded white calcareous fragments
NNA-5510	74.0-75.0	Dark brown-black lignitic claystone
NNA-5510	78.0-79.0	Dark brown-black lignitic claystone with minor fine sand
NNA-5510	103.0-104.0	Light grey claystone

APPENDIX 2. List of sample depths and preparation numbers for studied drill holes.

The prefix NNA denotes EMA/Vimy air core drill holes, NND the diamond core and CD the PNC diamond core drill hole

NNA-5605			
Sample Order by Prep. No.		Sample Order by Depth	
Sample Prep. No.	Depth (m)	Depth (m)	Sample Prep. No.
1I	41-42	41-42	1I
2I	46-47	46-47	2I
3I	50-51	50-51	3I
4I	54-55	54-55	4I
5I	56-57	56-57	5I
6I	60-61	60-61	6I
7I	62-63	62-63	7I
8I	64-65	64-65	8I

NNA-5738			
Sample Order by Prep. No.		Sample Order by Depth	
Sample Prep. No.	Depth (m)	Depth (m)	Sample Prep. No.
2K	49-50	49-50	2K
3K	52-53	52-53	3K
4K	59-60	59-60	4K
5K	61-62	61-62	5K
6K	64-65	64-65	6K
7K	70-71	70-71	7K
8K	72-73	72-73	8K
1L	91-92	91-92	1L
2L	98-99	98-99	2L

NND-5077			
Sample Order by Prep. No.		Sample Order by Depth	
Sample Prep. No.	Depth (m)	Depth (m)	Sample Prep. No.
7S	51.1	51.1	7S
8S	51.3	51.3	8S
1T	51.5	51.5	1T
2T	51.7	51.7	2T
3T	51.9	51.9	3T
4T	52.1	52.1	4T
5T	52.3	52.3	5T
7T	52.7	52.5	8T
8T	52.5	52.7	7T
1U	53.7	53.7	1U
2U	53.9	53.9	2U

NND-5028			
Sample Order by Prep. No.		Sample Order by Depth	
Sample Prep. No.	Depth (m)	Depth (m)	Sample Prep. No.
4P	37.5	37.5	4P
5P	39.1	39.1	5P
6P	39.6	39.6	6P
7P	40.5	40.5	7P
8P	41.5	41.5	8P
1Q	42.2	42.2	1Q
2Q	43	43	2Q
3Q	43.6	43.6	3Q
4Q	44.1	44.1	4Q
5Q	45	45	5Q
6Q	45.8	45.8	6Q
7Q	46.3	46.3	7Q
8Q	48.2	48.2	8Q
1R	48.4	48.4	1R
2R	58.3	58.3	2R
3R	58.5	58.5	3R

NNA-5507			
Sample Order by Prep. No.		Sample Order by Depth	
Sample Prep. No.	Depth (m)	Depth (m)	Sample Prep. No.
3L	47-48	47-48	3L
4L	52-53	52-53	4L
5L	54-55	54-55	5L
6L	59-60	59-60	6L
7L	71-72	71-72	7L
8L	73-74	73-74	8L

NND-5030			
Sample Order by Prep. No.		Sample Order by Depth	
Sample Prep. No.	Depth (m)	Depth (m)	Sample Prep. No.
4R	35.9	35.9	4R
5R	37.2	37.2	5R
6R	40.4	40.4	6R
7R	41.6	41.6	7R
8R	42.2	42.2	8R
1S	43	43	1S
2S	44.6	44.6	2S
3S	46.2	46.2	3S
4S	51.3	51.3	4S
5S	58.2	58.2	5S
6S	61.8	61.8	6S

CD-1-779			
Sample Order by Prep. No.		Sample Order by Depth	
Sample Prep. No.	Depth (m)	Depth (m)	Sample Prep. No.
7A	49.9-50	37.9-38	1E
8A	80.9-81	39.9-40	2E
1E	37.9-38	44.9-45	3E
2E	39.9-40	49.9-50	7A
3E	44.9-45	65.5-65.6	4E
4E	65.5-65.6	71.2-71.3	5E
5E	71.2-71.3	80.9-81	8A

NNA-5510			
Sample Order by Prep. No.		Sample Order by Depth	
Sample Prep. No.	Depth (m)	Depth (m)	Sample Prep. No.
3C	74.0-75.0	43-44	1M
4C	78.0-79.0	44-45	2M
1M	43-44	45-46	3M
2M	44-45	74.0-75.0	3C
3M	45-46	78.0-79.0	4C
8B	103.0-104.0	103.0-104.0	8B

APPENDIX 3. Species distribution and percentage occurrence in eight drill holes

Appendix Table 3.1 Species distribution and percentage occurrence in NNA-5605 (Princess). Percentages derived from 200-grain counts.

NNA-5605						
Depth	41.0-42.0	46.0-47.0	50.0-51.0	54.0-55.0	56.0-57.0	60.0-61.0
Lithological Interval	E3	E1	E1	Dc2	Dc1	Dc1
Species						
Cryptogam Spores						
Baculatisporites comaumensis	+					
Cyathidites australis		+		+		
C. minor				+	+	
Gleicheniidites circinidites		+	+	+	+	+
Laevigatosporites ovatus	+	+	+	+	+	+
Latrobosporites marginis				0.5	+	
Verrucatosporites speciosus			0.5			+
Gymnosperms						
Dacrycarpites australiensis			0.5	+		0.5
Lygistepollenites florinii	1	3	3	2.5	1.5	1.5
Phyllocladidites mawsonii		0.5	+	+		+
Podocarpidites ellipticus	6	4	1	1.5	0.5	+
Trichotomosulcites subgranulatus		+		+		
Angiosperms						
Ailanthipites paenestriatus		+			+	+
Anacolosidites acutullus					+	
Banksieaeidites arcuatus	+	2	1.5	+	0.5	+
B. cooksonii	0.5	0.5	+		+	0.5
B. davidsonii					+	
B. minimus						+
Beaupreaidites diversiformis	0.5				+	+
B. elegansiformis			+		+	
B. verrucosus	+	+	+		+	
Bluffopollis scabratus	+					0.5
Cupanieidites major				+		+
C. orthoteichus	0.5	+	+	0.5	+	0.5
C. reticularis	0.5			+		
Ericipites scabratus	+	+	+	1	0.5	0.5
Gothanipollis bassensis	+			1	+	
Haloragacidites harrisii	18	16.5	13	18	12.5	12
Ilexpollenites anguloclavatus	+		+		+	0.5
Liliacidites aviemorensis	3		+	1.5		1.5
Malvacipollis diversus	+	+	+	1.5	1	1
Myrtaceidites corymbiensis			+			
M. eucalyptoides		1	+	1.5	1	0.5
M. mesonesus	5	4	3.5	1.5	10	11
Nothofagidites brachyspinulosus/incrassatus	10	9	11	2.5	1	3.5
N. emarcidus/heterus	22.5	43.5	44.5	45.5	42.5	39.5

NNA-5605						
Depth	41.0-42.0	46.0-47.0	50.0-51.0	54.0-55.0	56.0-57.0	60.0-61.0
Lithological Interval	E3	E1	E1	Dc2	Dc1	Dc1
Species						
N. falcatus	4.5	4.5	4.5	2	5.5	3
N. senectus		0.5				
N. spp.			0.5			
Periporopollenites demarcatus			1.5	1.5	0.5	0.5
Polycolporopollenites esobalteus	1		0.5	+		
Proteacidites adenanthoides						+
P. annularis	+	0.5	+	+	0.5	1
P. carobelindiae				+		0.5
P. cirritulis	0.5	1	+		0.5	+
P. colubrimodus					+	
P. cumulus				+		
P. crassus		+	+	+	+	
P. aff. *Grevillea*						+
P. kopiensis						+
P. narnooensis	0.5	0.5	0.5			+
P. nasus			+	+	+	+
P. cf. *nitidus*		0.5			0.5	
P. obscurus		+	1.5	+		
P. pachypolus	+	+	+	3.5	1	0.5
P. protrudens				+		
P. pseudomoides		+				
P. reticulatus		+	+	+	+	+
P. rickmanii						+
P. subscabratus	+					
P. symphyonemoides	+					
P. tesselaria			+			
P. tuberculiformis				+	+	
P. spp.	4	1.5	3	4	1.5	4.5
Psilastephanocolporites micus					+	+
Rhoipites angurium	1		+			+
R. goulburnensis			+	0.5	0.5	
R. ivanhoensis					+	
R. microreticulatus	0.5				0.5	
R. minutiformis	1	1.5	2.5	4	5.5	9
R. muehlenbeckiaformis					+	
R. oralongii	+			+		
R. orbiculatus	+				+	
R. spp.					0.5	
Santalumidites cainozoicus	0.5		+	1	+	+
Sapotaceoidaepollenites rotundus	+	1	+	+	1	+
Schizocolpus marlinensis			+			

NNA-5605						
Depth	41.0-42.0	46.0-47.0	50.0-51.0	54.0-55.0	56.0-57.0	60.0-61.0
Lithological Interval	E3	E1	E1	Dc2	Dc1	Dc1
Species						
Tetracolporites palynius	1.5					
Tetracolporopollenites sp. (Milne 1988, Plate 6 O)				+		
Tricolpites incisus	0.5	0.5	0.5	+	+	+
T. occultum	3	0.5				1
T. reticularis	+					
T. secarius	+					
T. simatus					+	
T. thomasii					0.5	+
T. cf. *thomasii*					+	
T. spp.	2.5	0.5			0.5	
Tricolporites adelaidensis	0.5	+	+	+	+	+
T. leuros		+	+	+	+	
T. prolata	0.5	1	+		1	1
T. scabratus	1		1	1	+	+
T. spp.	8	0.5	3	2	6.5	3
Triporopollenites ambiguus						+
Gen. *et*. sp. indet.	1.5	1.5	2.5	1.5	2.5	2.5
Total	100	100	100	100	100	100

Appendix Table 3.2 Species distribution and percentage occurrence in NNA-5738. Percentages derived from 200-grain counts.

NNA-5738					
Depth	49.0-50.0	52.0-53.0	59.0-60.0	61.0-62.0	64.0-65.0
Lithological Interval	E2	E2	E3	E3	E3
Species					
Cryptogam Spores					
Baculatisporites comaumensis					+
Cyathidites australis	+			+	
C. minor		0.5	+		
Laevigatosporites ovatus			+	+	+
Monolites alveolatus					0.5
Verrucatosporites speciosus				+	+
Gymnosperms					
Dacrycarpites australiensis			0.5		+
Lygistepollenites florinii	1	0.5	0.5	0.5	+
Phyllocladidites mawsonii	+	0.5			+
Podocarpidites ellipticus	3.5		+	+	0.5
Trichotomosulcites subgranulatus					+
Angiosperms					
Ailanthipites paenestriatus	+		+	+	+
A. mulleri				+	+
Anacolosidites luteoides			+		
Banksieaeidites arcuatus	0.5	0.5	1.5		+
B. cooksonii	0.5		+	+	+
B. davidsonii	+			+	
Beaupreaidites diversiformis	+				
B. verrucosus			1		
Bluffopollis scabratus				+	+
Clavatipollenites glarius				0.5	1
Cupanieidites orthoteichus	1		+		+
Ericipites scabratus	1			0.5	
Gothanipollis bassensis	0.5		1	+	+
Haloragacidites harrisii	14.5	29.5	11	14.5	17
Liliacidites aviemorensis	2	0.5	2	3.5	3
Malvacipollis diversus	4.5	7	3	2	2
Myrtaceidites eucalyptoides	+		0.5	+	1
M. mesonesus	22	16.5	32.5	15	15.5
M. spp.			2		
Nothofagidites brachyspinulosis/incrassatus	1.5	1	1.5	4.5	4.5
N. emarcidus/heterus	30	22.5	15	42	37.5
N. falcatus	4.5	+	1.5	4	1
N. spinosus	+				
Periporopollenites demarcatus	+	0.5		+	0.5
Polycolporopollenites esobalteus	+			+	

NNA-5738					
Depth	49.0-50.0	52.0-53.0	59.0-60.0	61.0-62.0	64.0-65.0
Lithological Interval	E2	E2	E3	E3	E3
Species					
Proteacidites adenanthoides				0.5	
P. annularis	1.5	2.5	+	0	+
P. carobelindiae	+	+		+	+
P. cirritulis	3.5	4	1	0.5	+
P. crassus		0.5			+
P. aff. *Isopogon*					+
P. narnooensis					0.5
P. nasus					+
P. cf. *nitidus*					0.5
P. obscurus	+		+	0.5	+
P. pachypolus	+	+		+	0.5
P. cf. *pseudomoides*		+			
P. reticulatus				+	
P. cf. *reticulatus*	+				
P. cf. *rynthius*		+			
P. spp.	1	6.5	1	4	2
Psilastephanocolporites micus	+				
Rhoipites alveolatus					1
R. angurium			0.5	+	+
R. aralioides			+		
R. goulburnensis			1		+
R. ivanhoensis			+		
R. microreticulatus		+		+	+
R. minutiformis	3.5	1	5.5		2
R. orbiculatus					+
R. sphaerica	+				+
R. sp. A			0.5		
Santalumidites cainozoicus			0.5	+	+
Sapotaceoidaepollenites rotundus	0.5	1		+	+
Tetracolporites palynius		+			
Tricolpites incisus			+	0.5	+
T. cf. *phillipsii*				+	
T. reticularis			0.5		
T. thomasii				+	
T. spp.	0.5		0.5		
Tricolporites adelaidensis					+
T. angurium				+	
T. leuros				+	
T. microreticulatus	0.5	0.5			
T. prolata					0.5
T. scabratus			1.5		+

NNA-5738					
Depth	49.0-50.0	52.0-53.0	59.0-60.0	61.0-62.0	64.0-65.0
Lithological Interval	E2	E2	E3	E3	E3
Species					
T. spp.	0.5	2	9.5	6.5	8
Triporopollenites ambiguus	+				
Gen. *et.* sp. indet.	1.5	2.5	4.5	0.5	1
Total	100	100	100	100	100

Appendix Table 3.3 Species distribution and percentage occurrence in NND-5077. Percentages derived from 200-grain counts.

	NND-5077										
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1	E1
Species											
Cryptogam Spores											
Cyathidites australis			1		+	+				+	
Cyathidites minor		0.5								+	
Cyathidites spp.											
Dictyophyllidites equiexinus						+					
Gleicheniidites circinidites	+	+	+	+			0.5		+	1.5	+
Laevigatosporites ovatus	+			+					1.5	+	
Latrobosporites marginis	+		+	+					+	+	
Rugulatisporites sp.					+						
Verrucatosporites speciosus			+	+		+	+			+	
Verrucosisporites kopukuensis	+			+						+	
Spore sp. B										+	+
Gymnosperms											
Dacrycarpidites australiensis					+	+	0.5	+	0.5		
Lygistepollenites florinii	1	2	3	1.5	2	5.5	7.5	0.5	6.5	1.5	2.5
Parvisaccites catastus			+		+				+		
Phyllocladidites mawsonii	0.5	1	1	0.5	3	1.5	2.5		+		+
Podocarpidites ellipticus	1	3	0.5	0.5	2	4	4.5		2.5	1	0.5
Trichotomosulcites subgranulatus		0.5		0.5			0.5	0.5			
Angiosperms											
Ailanthipites mulleri								+			+

NND-5077											
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1	E1
Species											
A. paenestriatus	+		+	+	+		+			+	+
Anacolosidites acutullus					+						
Arecipites waitakiensis											+
Banksieaeidites arcuatus	0.5	+	1	1	0.5	+	+		+		+
B. cooksonii			+	+	+						+
B. davidsonii					+		+		0.5	+	+
Beaupreaidites diversiformis	+		+	+		+					
B. elegansiformis		+		+	+		+		+	+	+
B. verrucosus	+		+	+	+					+	
Bluffopollis scabratus	+	0.5	+	+	+	+	1.5				
Cupanieidites major				+							
C. orthoteichus					+	0.5					
C. reticularis					+						
Ericipites scabratus	+	+		+	0.5	+	0.5		0.5	+	+
Gothanipollis bassensis	0.5	0.5	0.5	+	0.5			0.5		0.5	+
Haloragacidites harrisii	12	10.5	12.5	17	14.5	12.5	18.5	6	28.5	12	9.5
Ilexpollenites anguloclavatus						0.5	1	2		+	
Liliacidites aviemorensis		1			1	1.5				1	
L. variegatus											
Malvacipollis diversus	1	1	+	0.5	1		+	1	1	0.5	
Myrtaceidites corymbiensis					+		+				
M. eucalyptoides	1.5	0.5	2		1		0.5		1	0.5	+
M. mesonesus	12.5	11.5	11	1.5	10.5	6.5	6.5	9.5		7.5	1.5

NND-5077											
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1	E1
Species											
Nothofagidites brachyspinulosus/incrassatus	2.5		5.5	3.5	2		4.5	6.5	+	1	0.5
N. emarcidus/heterus	45	51.5	42.5	49	50.5	56	36.5	41	40.5	47.5	68.5
N. falcatus	5	3	4	3.5	1	1.5	5.5		4	6.5	7.5
N. senectus	+	+	+		+			+			+
Periporopollenites demarcatus	+		+		+			+		+	+
Polycolporopollenites esobalteus				1				0.5			+
Propylipollis sp. A Milne 1988											+
P. sp. B Milne 1988		+		+							
Proteacidites adenanthoides			+	+		+					
P. annularis	+	0.5	0.5	1	0.5	2	1	1	+	2	1
P. carobelindiae	+	+	+	+	0.5	+	+		+	+	+
P. cirritulis	1	2.5	+		1	2	+	1	+	1.5	0.5
P. confragosus											+
P. crassus	+	+	+	+						+	+
P. crochetaria	+			+	+						
P. cumulus		+	+	+	+	+	+			+	+
P. aff. *Isopogon*	+			+			0.5			0.5	
P. narnooensis					+						
P. nasus										+	+
P. cf. *nitidus*	+		1								
P. obscurus	+	+	+	+			+		1	0.5	+
P. pachypolus	+	+		+	+		+	+	0.5		
P. pseudomoides							+			0.5	

NND-5077											
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1	E1
Species											
P. punctiporus					+						
P. reticulatus	+	0.5	+	+	0.5	+	+			+	+
P. cf. *P. reticulatus*				+							
P. rickmanii										+	+
P. rynthius	+									+	
P. scitus										+	
P. cf. *stipplatus*	+										
P. tenuiexinus	+										
P. tesselaria			+	+						+	
P. spp.	3	2	2	4.5	2	1	2.5	15	1.5	4.5	0.5
P. sp. E					+						+
P. sp. I						+					
Psilastephanocolporites micus	+			0.5	+					+	
Rhoipites angurium	1.5	+	1	+		+		7	1	+	
R. cissus											+
R. goulburnensis			0.5								
R. ivanhoensis	0.5	+					+	+			
R. microreticulatus	0.5							2			
R. minutiformis	3	1.5	3.5	2.5	2.5	0.5	1		0.5	3.5	2
R. orbiculatus											+
Santalumidites cainozoicus								+		0.5	+
R. sphaerica		0.5	0.5		1	+		+			
Sapotaceoidaepollenites rotundus	+		+		+	0.5	0.5	1.5		+	

NND-5077											
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1	E1
Species											
Schizocolpites marlinensis	0.5		0.5								
Tetracolporites palynius	+								+		+
T. sp. (Milne 1988)		+								+	+
Tricolpites incisus											0.5
T. occultum			0.5	0.5		0.5		0.5			
T. simatus	+									+	
T. spp.										0.5	1.5
T. sp. B										+	
Tricolporites adelaidensis	+				+				0.5	+	+
T. leuros	+	1.5	+	+		+	0.5		0.5	0.5	+
T. prolata	1	1	0.5	1.5	+	1.5	0.5	1.5	1.5		
T. scabratus				+	+		1	+	0.5		
T. spp.	4.5	1	4.5	6.5	1.5	1	1.5	2.5	5	4	2.5
Triporopollenites ambiguus	+	+			+	+				+	
T. delicatus						+					
T. robustus						1					
Gen. et. sp. indet.	1.5	2	0.5	3	0.5				0.5	0.5	1
Total	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 3.4 Species distribution and percent occurrence in NND-5028. Percentages derived from 200-grain counts.

	NND-5028													
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E3	E3	Dw4
Species														
Cryptogam Spores														
Cyathidites australis		+		+	+		+						0.5	
C. minor										+		+	+	
Baculatisporites comaumensis						1.5								
Gleicheniidites circinidites		+		1	+							+	+	
Laevigatosporites ovatus				+	0.5		0.5		+	+	0.5			
Peromonolites vellosus													+	
Verrucatosporites speciosus		+										+	+	
Spore spp.													+	
Gymnosperms														
Dacrycarpites australiensis				0.5	0.5		+						+	0.5
Lygistepollenites florinii		6	+	1	1.5	1	2	0.5	+		2	2	0.5	1
Parvisaccites catastus			0.5		+		+							
Phyllocladidites mawsonii							+		1				+	+
Podocarpidites ellipticus	2	3	2.5	1	7.5	5	4	2.5	5	1.5	2		+	+
P. puteus	+													
Trichotomosulcites subgranulatus										+	0.5		0.5	
Angiosperms														
Ailanthipites mulleri		+								+				
A. paenestriatus			+				+	+			+	+	+	+
Anacolosidites luteoides					+	1.5	+	0.5						

NND-5028														
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E3	E3	Dw4
Species														
Arecipites waitakiensis			+											
Banksieaeidites arcuatus		0.5		5	2	1.5	1.5	1	+	1	0.5	1.5	1.5	+
B. cooksonii		+					+		2.5	3.5	0.5			
B. davidsonii	+						+		+	3.5				
Beaupreaidites diversiformis		+	+	+	+	+					+			
B. elegansiformis			+	+	+	+	+		+				+	
B. verrucosus		+					1	+				+		
Bluffopollis scabratus			+								+	+	+	
Cupanieidites major			+				+						+	
C. orthoteichus					+			+						
C. reticularis	+													
Ericipites scabratus				0.5			+						1	1.5
Gothanipollis bassensis			+		0.5	+	0.5	3	0.5					+
Haloragacidites harrisii	55.5	17.5	40	12.5	7	2.5	8.5	6	11.5	25	35	26	7	4
Ilexpollenites anguloclavatus						0.5			+					+
I. verrucatus			+											
Liliacidites aviemorensis	1	0.5	2	1.5	2	1.5	1	+	0.5	0.5	0.5		0.5	1
Malvacipollis diversus	10	18.5	10.5	4.5	1	1		+	1.5	0.5	0.5	2	0.5	0.5
Myrtaceidites corymbiensis							+							+
M. eucalyptoides					2.5	6	+	4.5	10	2	2.5	1.5	1.5	1.5
M. mesonesus/parvus	2.5	9.5	11	23	33	53	22	41.5	23	11.5	9.5	6.5		
M. spp.														
Nothofagidites brachyspinulosus/incrassatus		2.5	2	1		1		6	5	4.5	6.5	6	+	1.5

NND-5028														
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E3	E3	Dw4
Species														
N. emarcidus/heterus	12.5	11.5	13.5	9	8.5	4.5	13	17	20.5	17.5	22.5	32	65	81
N. falcatus	0.5	1.5	+		+	+	0.5	+		1.5	3	1	+	3.5
Periporopollenites demarcatus		+		0.5			+						+	+
Polycolporopollenites esobalteus	0.5	0.5	0.5	0.5	+		0.5						0.5	
Propylipollis cf. *robustus*				+										
Proteacidites adenanthoides												+		
P. ambassadatus		0.5												
P. annularis									+			0.5	+	
P. carobelindiae														+
P. cirritulis	1.5	5	0.5	+	1.5	1.5	1		+		0.5	0.5		
P. confragosus			+											
P. crassus		2.5												
P. crochetaria							+							
P. cumulus				+			+					0.5		
P. cf. *grandis*		+												
P. aff. *Grevillea*												+		
P. aff. *Isopogon*													+	
P. leightonii														+
P. microspinosus		0.5												
P. narnooensis												+		
P. nasus								+	+			+		
P. cf. *P. nitidus*														
P. obscurus												+		

NND-5028														
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1	Dw4
Species														
P. pachypolus		0.5	+	+		+	0.5	+		+		+		0.5
P. protrudens		+												
P. pseudomoides							1							
P. reticulatus											+		+	+
P. cf. *reticulatus*														+
P. rynthius		+									0.5			
P. subscabratus														+
P. spp.	1.5	7	1	0.5	0.5		5	1.5	1.5	2.5	1	2.5	4.5	
Psilastephanocolporites micus			+	+	0.5		0.5							+
Rhoipites alveolatus			+	+	0.5		0.5		+					
R. angurium	0.5	0.5	1.5	5	1.5		4.5	0.5	0.5	0	+	2.5	1.5	+
R. aralioides					+									
R. cissus				+	+	+	+		+					
R. goulburnensis					2	0.5	1		0.5				+	
R. ivanhoensis			+		+	0.5	+			0.5	+			
R. microreticulatus				1		+				0.5	1.5			
R. minutiformis		2	2	8.5	6.5	2	13	5.5	4.5	7	1.5	1	4	2.5
R. sphaerica				1	+		0.5	1.5	1					
R. spp.					1									
Santalumidites cainozoicus	+	1	0.5	1			+	0.5					+	
Sapotaceoidaepollenites rotundus	0.5	+	+	+	+	0.5	1	+	+	0.5		+	+	
Schizocolpites marlinensis						0.5								
Sparganiaceaepollenites barungensis														0.5

NND-5028														
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1	Dw4
Species														
Tetracolporites palynius		+						+				+	+	
T. sp. Milne 1988			+											
Tricolpites confessus									+			0.5		
T. incisus				1		0.5		0.5	0.5				+	+
T. occultum	2			1			0.5		1	2.5		0.5	+	+
T. cf. *phillipsii*					+								2	
T. reticularis			0.5	0.5			+	+						
T. secarius				+	0.5									
T. simatus					+									
T. thomasii							+							+
T. cf. *thomasii*		1								+				
T. spp.	0.5			2	1							0.5		
T. sp. A							+							
Tricolporites adelaidensis				+		+					0.5	0.5	+	
T. leuros					1	0.5	+		0.5	1		+	+	+
T. prolata		0.5	0.5		2.5	5.5	5	0.5	2.5	6	3	3	0.5	
T. scabratus					+	+	2	1.5	1	1	0.5	0.5		
T. spp.	6.5	6	8.5	13	10	4	7	3.5	5	2	2	5.5	7.5	0.5
T. sp. A				+										
Triporopollenites vargus					+									
Gen. *et*. sp. indet.	1.5	1.5	2.5	4	4.5	3.5	2	2		3.5	3	3	1	
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 3.5 Species distribution and percentage occurrence in NNA-5507. Percentages derived from 200-grain counts.

NNA-5507				
Depth	47.0-48.0	52.0-53.0	54.0-55.0	59.0-60.0
Lithological Interval	E2	E1	E1	Dw3
Species				
Spores				
Cyathidites australis	+			
C. sp.		+		
Gleicheniidites circinidites				+
Laevigatosporites ovatus		+		+
Verrucatosporites speciosus	+	+	+	
Gymnosperms				
Dacrycarpidites australiensis		0.5	0.5	
Lygistepollenites florinii	2	2	4	+
Parvisaccites catastus		0.5		
Phyllocladidites mawsonii		+	+	+
Podocarpidites ellipticus	4.5	6	3	1
P. spp.				0.5
Trichotomosulcites subgranulatus	+			
Angiosperms				
Ailanthipites paenestriatus	+	+	+	0
Anacolosidites acutullus				0.5
Banksieaeidites arcuatus	+	2	0.5	3
B. cooksonii	+	+	0.5	+
B. davidsonii			+	
Beaupreaidites diversiformis		+		+
B. verrucosus		+	+	+
Bluffopollis scabratus		+		+
Cupanieidites orthoteichus	0.5	+	+	
Ericipites scabratus		+	+	0.5
Haloragacidites harrisii	10	6.5	11	1.5
Ilexpollenites anguloclavatus		0.5		
Liliacidites aviemorensis	0.5	0.5	1	
Malvacipollis diversus	2.5	1	0.5	0.5
Myrtaceidites eucalyptoides		0.5	+	0.5
M. mesonesus/parvus	26.5	12	6.5	14
M. spp.				1
Nothofagidites brachyspinulosis/incrassatus	8.5	5	5	5
N. emarcidus/heterus	24.5	31	50	38
N. falcatus		4	1.5	3.5
Periporopollenites demarcatus	1	+		1.5
Polycolporopollenites esobalteus				+
Proteacidites adenanthoides	+			
P. ambassadatus	+			

NNA-5507				
Depth	47.0-48.0	52.0-53.0	54.0-55.0	59.0-60.0
Lithological Interval	E2	E1	E1	Dw3
Species				
P. annularis	0.5	0.5	+	+
P. carobelindiae	0	+		+
P. cirritulis	0.5	0.5	1	1.5
P. crassus	+			0.5
P. cumulus		+		
P. narnooensis		1	1	
P. nasus				+
P. obscurus			+	0.5
P. pachypolus		+	+	5
P. reticulatus		+	+	+
P. rynthius				0.5
P. tesselaria	0.5			
P. spp.	4	2.5	4.5	5
Psilastephanocolporites micus		0.5		1.5
Rhoipites angurium		1	+	0.5
R. cissus		0.5		
R. fragilis			+	
R. goulburnensis		1		+
R. hawkdunensis	+			
R. microreticulatus	1	1		0.5
R. minutiformis	6.5	4.5	2	4
R. orbiculatus			+	
Santalumidites cainozoicus	+	+	+	+
Sapotaceoidaepollenites rotundus	+	+	0.5	+
Tetracolporites palynius	+		0.5	0.5
Tricolpites confessus		0.5		
T. incisus		1	+	0.5
T. occultum	1.5			0.5
T. thomasii	0.5			
T. spp.		1	0.5	2
Tricolporites adelaidensis		+		+
T. leuros	+	+	+	+
T. prolata		1.5		
T. scabratus	+	+		
T. spp.	3.5	9	3.5	3.5
Gen *et*. sp. indet.	1	2	2.5	2.5
Total	100	100	100	100

Appendix Table 3.6 Species distribution and percentage occurrence in NND-5030. Percentages derived from 200-grain counts.

NND-5030							
Depth	37.2	41.6	42.2	46.2	51.3	58.2	61.8
Lithological Interval	E2	E2	E2	Dc3	Dc2	Dw3	Dw3
Species							
Cryptogam Spores							
Cyathidites australis		+					
Cyathidites minor							+
C. sp.							0.5
Gleicheniidites circinidites				+	0.5		
Laevigatosporites ovatus	+	0.5		+	+	+	0.5
Latrobosporites marginis				+			
Peromonolites vellosus						+	
Verrucatosporites speciosus					+		
Gymnosperms							
Dacrycarpites australiensis	1.5	0.5			0.5		
Lygistepollenites florinii	0.5	2.5	2	3.5	2	0.5	0.5
Parvisaccites catastus		+					
Phyllocladidites mawsonii				+	1		
Podocarpidites ellipticus		6	1.5	2	3.5	2	1
P. spp.		5.5					
Trichotomosulcites subgranulatus			0.5				+
Angiosperms							
Ailanthipites paenestriatus	+	+	+	+	+	+	
Anacolosidites acutullus				0.5			0.5
A. luteoides	1						
Banksieaeidites arcuatus	1.5	+		1.5	0.5	+	0.5
B. cooksonii		2.5	1.5	1	+		
B. davidsonii		+	+				
Beaupreaidites diversiformis			+				+
B. elegansiformis	+			+			
B. verrucosus	0.5	+					
Bluffopollis scabratus					+		+
Cupanieidites major						+	
C. orthoteichus	0.5		+		1.5	2	0.5
C. reticularis		1					1
Ericipites scabratus	+		+				
Gothanipollis bassensis		1			+		1
Haloragacidites harrisii	6.5	14.5	29.5	22	12	3	6.5
Ilexpollenites anguloclavatus	+					0.5	
Liliacidites aviemorensis	3.5	1	1		0.5	0.5	1
L. variegatus						+	
Malvacipollis diversus	1.5	+	4.5	1	2	1.5	
Myrtaceidites corymbiensis				0.5			0.5
M. eucalyptoides	+	0.5	+	0.5	0.5	0.5	1.5

NND-5030							
Depth	37.2	41.6	42.2	46.2	51.3	58.2	61.8
Lithological Interval	E2	E2	E2	Dc3	Dc2	Dw3	Dw3
Species							
M. mesonesus/parvus	44.5	24	16	2.5	11	24	31.5
Nothofagidites brachyspinulosus/incrassatus	+	1.5	3	2.5	2.5	1	2
N. emarcidus/heterus	4.5	18.5	16.5	32.5	37	46.5	29
N. falcatus		1	1	1	2.5	0.5	1
N. senectus				+		+	
Periporopollenites demarcatus					+	1.5	1
Polycolporopollenites esobalteus	+	+		0.5			
Propylipollis cf. *robustus*	+						
Proteacidites ambassadatus					+		
P. annularis				0.5	+	+	+
P. carobelindiae					+	+	
P. cirritulis	0.5	+	1		+	1.5	1
P. crassus	+		+		+		+
P. crochetaria	+						
P. aff. *Isopogon*					+		
P. ivanhoensis				+			
P. cf. *leightonii*			+		+		
P. narnooensis			0.5				
P. nasus					+	+	
P. cf. *nitidus*	0.5	0.5					
P. obscurus					+		
P. pachypolus	0.5	+	+		+	4	1
P. pseudomoides							+
P. reticulatus		+			+		
P. cf. *reticulatus*			+				
P. rynthius	+						
P. spp.	3	1.5	3.5	4.5	0.5	1.5	2.5
P. sp. H					+		
Psilastephanocolporites micus		+	+		0.5	0.5	+
Rhoipites alveolatus	0.5						
Rhoipites angurium			+	3.5	0.5	0.5	1.5
R. cissus				+	+		
R. fragilis					+		
R. goulburnensis	1		+	0.5	+	+	0.5
R. ivanhoensis			+	0.5	+		+
R. microreticulatus			0.5	0.5			0.5
R. minutiformis	8.5	7	10.5	4	4.5	2.5	7
R. oralongii		+					
R. orbiculatus					+		+
R. sphaerica		+			0.5	+	+
Santalumidites cainozoicus			+				
Sapotaceoidaepollenites rotundus	0.5	+		+	1.5	+	0.5

NND-5030							
Depth	37.2	41.6	42.2	46.2	51.3	58.2	61.8
Lithological Interval	E2	E2	E2	Dc3	Dc2	Dw3	Dw3
Species							
Schizocolpus marlinensis	+						
Tetracolporites palynius					+		
T. spp. (Milne 1988)	+						
Tricolpites incisus	0.5			+	1.5		0.5
T. occultum	1	0.5	3.5				
T. phillipsii	+						
T. reticularis	+						
T. simatus		+					
T. thomasii		+			+		
T. spp.	2	0.5			0.5	1	
Tricolporites adelaidensis				+	0.5	+	
T. leuros		+			+		
T. prolata	5	1.5		1.5	3	0.5	0.5
T. scabratus	0.5	1	0.5	+			
T. spp.	7.5	4.5	2.5	10	6	3.5	2.5
Gen. *et*. sp. indet.	2.5	2.5	0.5	3	3	0.5	2
Total	100	100	100	100	100	100	100

Appendix Table 3.7 Species distribution and percentage occurrence in CD-1-779. Percentages derived from 200-grain counts.

CD-1-779					
Depth	39.9-40.0	44.9-45.0	65.5-65.6	71.2-71.3	80.9-81.0
Lithological Interval	E3	E2	Dc2	Dc2	Dw4
Species					
Spores					
Baculatisporites comaumensis			+	+	1
Cyathidites australis			0.5	+	+
C. minor			+	+	
Dictyophyllidites equiexinus				+	
Gleicheniidites circinidites			+		
Laevigatosporites ovatus	0.5		0.5	+	0.5
Latrobosporites marginis		0.5	+		
Neoraistrickia cf. *levidensis*	+				+
Verrucatosporites speciosus		+			
Verrucosisporites cristatus			+	+	
Gymnosperms					
Dacrycarpites australiensis		0.5			
Lygistepollenites florinii	+	0.5	1	+	1
Parvisaccites catastus	+	+			
Phyllocladidites mawsonii			0.5	0.5	
Podocarpidites ellipticus	0.5	3	+	2	1
Trichotomosulcites subgranulatus		+			
Angiosperms					
Ailanthipites paenestriatus	+		0.5		
Anacolosidites acutullus			+	+	
Banksieaeidites arcuatus	+	0.5	1	0.5	
B. cooksonii		+		+	+
B. davidsonii		+			+
Beaupreaidites diversiformis		+	+	+	
Bluffopollis scabratus			+	+	
Cupanieidites major			+		
C. orthoteichus	+		1.5	1	1
C. reticularis	1	+		+	0.5
Ericipites scabratus	+		0.5	+	
Gothanipollis bassensis	1.5		+	0.5	
Haloragacidites harrisii	5	14.5	4	9.5	5.5
Ilexpollenites megagemmatus	0.5				
Liliacidites aviemorensis	1	0.5		0.5	
L. variegatus					0.5
Malvacipollis diversus	13	2	0.5	+	1
M. subtilis	1			0.5	
Myrtaceidites corymbiensis			1.5	+	1
M. eucalyptoides	3	3		0.5	

CD-1-779					
Depth	39.9-40.0	44.9-45.0	65.5-65.6	71.2-71.3	80.9-81.0
Lithological Interval	E3	E2	Dc2	Dc2	Dw4
Species					
M. mesonesus/parvus	48	32	33	36.5	32
Nothofagidites brachyspinulosus/incrassatus	6	13.5	11	11	8
N. emarcidus/heterus	6.5	13	15.5	16	26
N. falcatus		1.5	0.5		0.5
N. vansteenisii		1.5	2.5	1	3
Periporopollenites demarcatus	+	+	0.5	4	1
Polycolporopollenites esobalteus	+		+	+	
Propylipollis biporous					+
P. cf. *robustus*					+
Proteacidites adenanthoides					0.5
P. ambassadatus		+			
P. annularis		+	0.5	+	1.5
P. carobelindiae		+	+	+	
P. cirritulis	+	1		2	1.5
P. colubrimodus			+	+	+
P. confragosus	+		+	+	
P. crassus		+	2	1.5	
P. crochetaria	+				
P. cumulus		+			+
P. leightonii			+		
P. microspinosus		+	+		
P. narnooensis		+			
P. nasus					
P. nasus (small)	+		+		
P. cf. *nexinus*			+		
P. cf. *nitidus*				0.5	
P. cf. *notredamus*	+				
P. obscurus		+	+	+	
P. ornatus	+				
P. pachypolus	1	+	1.5	+	0.5
P. polygonalis	+				
P. protrudens	+				
P. pseudomoides				+	
P. cf. *pseudomoides* sp. 1					1
P. rectomarginis			+		
P. rectus					+
P. reticulatus	+	+	+	+	
P. cf. *reticulatus*		+			
P. rynthius			+		+
P. subscabratus		+			
P. tesselaria		+			

CD-1-779					
Depth	39.9-40.0	44.9-45.0	65.5-65.6	71.2-71.3	80.9-81.0
Lithological Interval	E3	E2	Dc2	Dc2	Dw4
Species					
P. vaga		+			+
P. spp.	1.5	1	3	2.5	
P. sp. C					2
Psilastephanocolporites micus	+			1	
Rhoipites alveolatus	+		+	+	+
R. angurium	+	+	1	0.5	1
R. cissus			+		
R. fragilis		+	+		
R. goulburnensis			+		+
R. hawkdunensis		+			
R. ivanhoensis		+	0.5		1
R. microreticulatus	+		+	+	1
R. minutiformis	2	5.5	2	2	
R. cf. *muehlenbeckiaformis*		+			
R. orbiculatus		+			
R. spp.					0.5
Santalumidites cainozoicus		+		+	1
Sapotaceoidaepollenites rotundus	4.5	0.5	+	+	1.5
Schizocolpus marlinensis				0.5	+
Tetracolporites palynius		+			
T. spp.	+	+			
Tricolpites incisus	+		0.5	+	1
T. occultum	+		2.5	+	
T. simatus		+			
T. thomasii		+			
T. spp.	+		+		
Tricolporites adelaidensis		+			
T. leuros		+			0.5
T. prolata					+
T. scabratus		+			
T. sphaerica		+	0.5		
Tricolporites spp.	1.5	3.5	7.5	4.5	0.5
Triporopollenites ambiguus			+		
T. apiculatus					+
Gen *et*. sp. indet.	2	2	3.5	1	1.5
Total	100	100	100	100	100

Appendix Table 3.8 Species distribution and percentage occurrence in NA-5510. Percentages derived from 200-grain counts.

NNA-5510					
Depth	43.0-44.0	44.0-45.0	45.0-46.0	74.0-75.0	78.0-79.0
Lithological Interval	E2	E2	E2	Dc2	Dc2
Species					
Spores					
Baculatisporites comaumensis		0.5			
Cyathidites australis	+				
C. minor			0.5		
Gleicheniidites circinidites	+	0.5			
Laevigatosporites ovatus	+	1		0.5	
Verrucatosporites speciosus				+	
Gymnosperms					
Dacrycarpidites australiensis	+	0.5	0.5	0.5	
Lygistepollenites florinii	5	2.5	4	0.5	+
Parvisaccites catastus	0.5	+			
Phyllocladidites mawsonii		0.5	0.5	2.5	
Podocarpidites ellipticus	6	7	5	0.5	+
P. puteus	+				
Trichotomosulcites subgranulatus	0.5	0.5		0.5	
Angiosperms					
Ailanthipites mulleri	+		+		
A. paenestriatus	+		+	1	1.5
Anacolosidites luteoides		0.5	+		
Banksieaeidites arcuatus	1		+	2	2.5
B. cooksonii	4.5	4		+	
B. davidsonii	+	0.5			
Beaupreaidites diversiformis			+		
B. verrucosus	+			+	+
Bluffopollis scabratus	0.5	+	+		
Cupanieidites major					
C. orthoteichus				+	+
C. reticularis				1	1
Ericipites scabratus				1.5	0.5
Gothanipollis bassensis	0.5	1	0.5		+
Haloragacidites harrisii	11	9	14.5	1.5	7.5
Ilexpollenites anguloclavatus				1	+
Liliacidites aviemorensis		3		+	+
Malvacipollis diversus	0.5	2	6.5	0.5	0.5
Myrtaceidites eucalyptoides	0.5	1	0.5		1
M. mesonesus/parvus	25	28.5	14	13	20
Nothofagidites brachyspinulosus/incrassatus	3.5	3	7.5	18.5	13.5
N. emarcidus/heterus	10.5	9.5	30	23.5	26.5
N. falcatus	1	0.5	0.5	1.5	2.5

NNA-5510					
Depth	43.0-44.0	44.0-45.0	45.0-46.0	74.0-75.0	78.0-79.0
Lithological Interval	E2	E2	E2	Dc2	Dc2
Species					
N. senectus				+	+
N. vansteenisii				+	
Periporopollenites demarcatus	1	+		+	1
Polycolporopollenites esobalteus		+		+	+
Propylipollis cf. *robustus*				+	+
Proteacidites annularis				1.5	2.5
P. bremerensis					
P. carobelindiae		+			+
P. cirritulis	1	3	1.5	0.5	2
P. colubrimodus					
P. confragosus		+	+		
P. crassus	+		+	+	0.5
P. ivanhoensis				0.5	
P. leightonii				+	
P. microverrucatus				+	
P. narnooensis	2.5	2		+	
P. nasus	+		+		
P. nasus (small)				1	
P. obscurus				0.5	1
P. pachypolus	+	+	0.5	2	2.5
P. polygonalis				+	
P. pseudomoides					2
P. cf. *pseudomoides* sp. 1				4	
P. cf. *pseudomoides* sp. 2			0.5		
P. reticulatus	+				
P. rynthius		0.5			
P. tenuiexinus					0.5
P. vaga				0.5	0
P. spp.	4.5	2.5	0.5	2.5	1.5
Psilastephanocolporites micus	0.5				
Rhoipites alveolatus					+
R. angurium	0.5	1	0.5	3	+
R. goulburnensis				1.5	0.5
R. ivanhoensis			+		+
R. microreticulatus		0.5			3
R. minutiformis	6	4	3.5	7.5	1.5
R. oralongii		1			
R. rotundiformis	+				
R. spp.				0.5	0.5
Santalumidites cainozoicus	0.5	+	+		0.5
Sapotaceoidaepollenites rotundus	1.5	0.5	+	+	+

NNA-5510					
Depth	43.0-44.0	44.0-45.0	45.0-46.0	74.0-75.0	78.0-79.0
Lithological Interval	E2	E2	E2	Dc2	Dc2
Species					
Schizocolpus marlinensis		0.5		0.5	+
Tetracolporites palynius			+		
Tricolpites incisus	+	0.5	+	+	+
T. occultum	2	1	1		
T. reticularis				0.5	
T. thomasii	+	+			
T. spp.				0.5	
Tricolporites adelaidensis		+			
T. leuros	+		+	0.5	+
T. prolata	0.5		0.5		1
T. scabratus	+	+			
T. sphaerica				1	1
T. spp.	7.5	6	4		
Gen. et. sp. indet	1.5	1.5	3	1.5	1.5
Total	100	100	100	100	100

APPENDIX 4. Register of illustrated fossil specimens of previously described species.

Authors listed in Appendix 9.

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
Cryptogam Spores							
Baculatisporites comaumensis	1	A, B	CD-1-1/67–67.1	8/2	6.0/127.3	U27/0	F52737
Cibotiidites tuberculatus	1	C, D	CD-1-1/35.0–35.1	4F/2	19.7/130.9	F31/0	F52738
Cyathidites australis/minor	1	E, F	NND-5077/53.7	1U/1	16.4/149.3	J50/3	F52739
Dictyophyllidites equiexinus	1	G	CD-1-779/71.2–71.3	5E/1	3.8/153.4	W54/3	F52740
Gleicheniidites circinidites	1	H	CD-1-779/65.5–65.6	4E/1	2.5/139.9	Y40/2	F52741
Laevigatosporites ovatus	1	I, J	NNA-5025/72–73	7B/2	10.2/151.3	Q52/0	F52251
" "	1	K	OF-1-52/58-60	5B/2	5.1/141.7	V42/0	F52740
Latrobosporites marginis	1	L–N	NND-5077/53.7	1U/1	13.1/138.7	N39/0	F52743
L. ohaiensis	2	A, B	CD-1-779/71.2–71.3	5E/1	1.5/129.4	Z29/2	F52744
Monolites alveolatus	2	C, D	NNA-5738/64–65	6K/2	9.8/133.2	Q33/0	F52745
Neoraistrickia cf. *levidensis*	2	E, F	CD-1-779/39.9–40	2E/1	20.0/148.1	F49/1	F52746
Peromonolites vellosus	2	G, H	NND-5030/58.2	5S/1	15.7/133.5	K34/3	F52747
Punctatosporites cf. *scabratus*	2	I, J	CD-1-409/30.95–31.08	6D/2	18.1/158.7	H60/1	F52748
Rugulatisporites micraulaxis	3	E, F	CD-1-481/40.9–41	2/1	8.3/124.0	S24/1	F52749
Verrucatosporites speciosus	2	K, L	OF-1-52/58-60	5B/2	10.2/163.0	Q64/0	F52750
Verrucosisporites cristatus	3	A, B	CD-1-779/71.2–71.3	5E/1	11.8/151.8	O52/4	F52751
V. kopukuensis	3	C, D	NND-5077/51.1	7S/1	10.6/123.7	P23/4	F52752
Gymnosperms							
Bisaccate							
Lygistepollenites florinii	3	G, H	NND-5077/53.9	2U/2	16.7/151.5	J52/0	F52753
" "	4	A, B	NNA-5738/49–50	2K/1	21.3/148.5	D49/4	F52754
Parvisaccites catastus	4	C, D	NND-5077/51.5	1T/1	6.5/141.7	U42/1	F52755
" "	4	E, F	CD-1-779/44.9–45	3E/2	20.1/161.8	F63/0	F52756
Phyllocladidites mawsonii	4	G, H	NNA-5606/46–47	2I/2	7.9/143.1	S43/4	F52757

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
Phyllocladidites mawsonii	4	I, J	CD-1-763/45.2–45.3	4/3	18.9/158.0	G59/0	F52758
Podocarpidites ellipticus	4	K, L	NND-5030/51.3	4S/1	5.1/132.9	V33/0	F52759
" "	4	M	NNA-5606/46–47	2I/1	16.9/155.2	J56/0	F52760
P. puteus	4	N, O	CD-1-481/40.9–41	2/1	9.9/153.4	Q54/0	F52761
Trisaccate							
Dacrycarpites australiensis	4	P, Q	NNA-5605/50–51	3I/2	20.2/161.9	F63/1	F52762
Trichotomosulcites subgranulatus	4	R, S	CD-1-779/44.9–45	3E/2	17.1/158.5	J59/0	F52763
Angiosperms							
Monocolpate-Monosulcate-Monoporate							
Aglaoreidia qualumis	5	A, B	CD-1-1360/40.9–41	5D/2	17.9/152.6	H53/0	F52764
Arecipites subverrucatus	5	E, F	CD-1-481/42.1–42.2	3F/1	10.0/146.1	Q47/3	F52765
A. waitakiensis	5	G–I	NND-5077/53.9	2U/1	9.2/143.9	R44/0	F52766
Clavatipollenites ascarinoides	5	C, D	RC-0277/70–72	7F/1	13.0/145.4	N46/0	F52767
Liliacidites aviemorensis	5	J–L	NND-5030/37.2	5R/2	7.8/128.9	S29/0	F52768
L. variegatus	5	M, N	CD-1-1/35.0–35.1	4F/1	7.9/164.2	S65/4	F52252
Sparganiaceaepollenites barungensis	5	O–Q	OF-1-52/58-60	5B/2	10.2/126.0	Q26/1	F52769
Tricolpate							
Perfotricolpites digitatus	5	T–V	CD-1-481/38.9–39	2F/1	11.6/140.7	O41/0	F52770
Tricolpites confessus	5	R, S	CD-1-1485/40.6–40.7	4A/2	10.0/154.7	Q55/4	F52771
T. incisus	5	W, X	NNA-5605/56–57	5I/2	10.7/142.7	P43/4	F52772
" "	5	Y	CD-1-779/65.5–65.6	4E/1	8.9/154.3	R55/0	F52773
" "	5	Z–BB	RC-0277/70–72	7F/1	19.9/140.6	F41/1	F52774
T. cf. *lilliei*	6	A, B	RC-0277/70–72	7F/2	15.3/161.6	L63/1	F52775
T. perlongicolpus	6	C–E	CD-1-1/40–40.1	1A/1	14.9/126.0	L26/1	F52776
T. phillipsii	6	F	NND-5030/37.2	5R/2	5.4/155.7	V56/2	F52777

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
T. cf. *reticulatus*	6	G, H	RC-0672/50–52	2H/1	12.3/153.0	O54/1	F52778
T. secarius	6	I–K	OF-1-52/58-60	5B/2	2.9/139.4	Y39/2	F52779
T. simatus	6	L–N	CD-1-779/44.9–45	3E/1	5.2/142.3	V43/3	F52780
T. thomasii (syncolpate)	6	Q, R	NNA-5605/60–61	6I/1	20.4/142.5	E43/0	F52781
T. cf. *thomasii*	6	O, P	NNA-5605/56–57	5I/1	22.2/157.9	D59/1	F52782
Tricolporate							
Ailanthipites mulleri	7	A, B	NND-5077/52.3	6T/2	20.7/133.6	E34/1	F52783
" "	7	C–E	NNA-5738/64–65	6K/1	19.9/147.1	F48/0	F52784
A. paenestriatus	7	F, G	NNA-5507/52–53	4L/2	9.3/124.4	R24/2	F52785
" "	7	H–J	NNA-5738/64–65	6K/1	15.9/154.9	K56/0	F52786
Ilexpollenites anguloclavatus	7	N, O	CD-1-1485/38.9–39.0	3D/2	12.1/136.2	O36/2	F52788
" "	7	P, Q	NNA-5605/56–57	5I/2	9.9/132.4	Q32/4	F52789
" "	7	R	NNA-5025/72–73	7B/2	13.0/156.5	M57/0	F52790
I. megagemmatus	7	S, T	CD-1-779/39.9–40	2E/1	9.9/163.9	Q65/3	F52791
I. verrucatus	7	U, V	CD-1-481/38.9–39	2F/2	2.4/138.1	Y38/0	F52792
Rhoipites alveolatus	7	W,X	RC-0672/44–46	1H/2	19.0/127.4	G27/0	F52276
" "	7	Y	RC-0672/44–46	1H/1	21.0/133.5	E34/1	F52793
" "	7	Z–BB	CD-1-779/71.2–71.3	5E/1	2.3/153.4	Y54/0	F52794
R. angurium	7	CC, DD	CD-1-1/67–67.1	8/2	14.9/143.7	L44/0	F52277
R. cf. *aralioides*	8	A–D	NNA-5738/59–60	4K/2	21.9/155.4	D56/0	F52795
R. cissus	8	E, F	NND-5077/53.9	2U/1	5.6/136.1	U36/4	F52796
" "	8	G–I	NNA-5507/52–53	4L/2	10.9/134.2	P34/0	F52797
R. fragilis	8	J, K	CD-1-779/44.9–45	3E/1	7.1/151.5	T52/0	F52798
R. goulburnensis	8	O, P	CD-1-779/80.9–81	8A/1	16.1/131.3	K31/2	F52278
" "	8	Q–S	CD-1-481/38.9–39	2F/1	16.9/151.3	J52/0	F52799

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
R. hawkdunensis	8	L–N	RC-0672/50–52	2H/2	13.7/133.0	M33/0	F52799
R. ivanhoensis	8	Z–BB	NNA-5738/59–60	4K/2	15.2/135.1	L35/0	F52800
R. microreticulatus	8	T–V	NND-5028/43	2Q/1	9.8/160.4	Q61/4	F52801
" "	8	W–Y	NND-5030/61.8	6S/1	4.6/160.4	W61/2	F52802
R. minutiformis	8	CC, DD	NND-5030/51.3	4S/1	4.2/126.2	W26/0	F52803
" "	8	EE, FF	NND-5030/61.8	6S/1	3.2/138.4	X39/1	F52804
R. muehlenbeckiaformis	8	GG–II	NNA-5605/56–57	5I/2	12.1/152.4	O53/0	F52805
R. rotundiformis	8	JJ, KK	NND-5028/43	2Q/1	11.9/140.2	O41/3	F52806
R. sphaerica	9	T	NND-5028/44.1	4Q/1	5.2/152.8	V53/4	F52807
Schizocolpus marlinensis	9	A–C	CD-1-779/80.9–81	8A/1	9.7/127.0	Q27/3	F52808
Tricolporites adelaidensis	9	D–F	NNA-5605/56–57	5I/2	7.9/139.0	S39/4	F52809
" "	9	G, H	CD-1-1485/38.9–39.0	3D/1	13.8/143.9	M44/4	F52810
T. cf. *cooksonii*	9	I–K	NND-5030/61.8	6S/2	18.0/157.7	H59/1	F52811
T. leuros	9	L	RC-0672/50–52	2H/2	6.8/127.0	T27/0	F52813
" "	9	M	RC-0672/50–52	2H/2	14.1/154.2	M55/0	F52814
T. prolata	9	P, Q	CD-1-481/42.1–42.2	3F/1	21.1/140.4	E41/1	F52815
" "	9	R, S	NND-5028/43	2Q/1	7.0/164.1	T65/0	F52816
T. pelargonoides	9	N, O	CD-1-481/40.9–41	2/1	7.0/151.4	T52/0	F52812
T. scabratus	9	U, V	NNA-5605/56–57	5I/2	11.8/146.4	O47/0	F52817
T. valvatus	9	W	RC-0672/52–54	3H/2	16.7/123.1	K23/1	F52818
Syncolpate-Syncolporate							
Cupanieidites major	10	A, B	CD-1-763/54.9–55	5/2	6.2/156.4	U57/0	F52820
" "	10	C, D	NNA-5605/60–61	6I/2	4.8/145.9	V46/4	F52821
C. orthoteichus	10	E, F	CD-1-481/42.1–42.2	3F/2	11.8/136.3	O36/4	F52822
C. reticularis	10	G	CD-1-779/39.9–40	2E/1	14.1/127.1	M27/0	F52823

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
C. reticularis	10	H–J	RC-0672/50–52	2H/2	13.2/155.4	N56/0	F52824
Gothanipollis bassensis	10	K, L	CD-1-763/72.8–72.9	7/1	10.0/151.7	Q52/0	F52825
Myrtaceidites eucalyptoides	10	M–O	NNA-5605/46–47	2I/2	10.0/144.0	Q44/0	F52826
M. mesonesus/parvus	10	P, Q	NNA-5605/50–51	3I/1	3.4/137.3	X37/2	F52827
Polycolpate							
Nothofagidites brachyspinulosus/incrassatus	10	R–T	NNA-5606/46–47	2I/2	10.2/152.6	Q53/0	F52828
" "	10	U–W	NNA-5606/46–47	2I/1	20.9/157.2	E58/0	F52829
N. emarcidus/heterus	10	X, Y	CD-1-481/38.9–39	2F/1	16.1/142.9	K43/2	F52261
" "	10	Z	NND-5077/52.7	7T/2	13.5/140.5	M41/3	F52830
" "	11	A	NND-5077/52.1	4T/2	5.8/157.1	U58/3	F52831
N. falcatus	11	B–D	NND-5077/51.1	7S/1	3.5/140.4	X41/1	F52832
" "	11	E–G	NNA-5605/50–51	3I/1	8.6/138.3	R39/3	F52833
N. longispinosus	11	H, I	CD-1-481/42.1–42.2	3F/2	11.2/162.0	P63/0	F52834
N. senectus	11	J–L	CD-1-481/38.9–39	2F/2	9.2/143.7	R44/0	F52835
N. spinosus	11	M–O	NNA-5738/49–50	2K/2	6.4/151.5	U52/0	F52836
N. vansteenisii	11	P–R	NNA-5510/74–75	3C/2	8.0/141.7	S42/0	F52837
Polycolporate							
Polycolporopollenites esobalteus	11	T–W	CD-1-1/67–67.1	8/2	14.3/135.3	M35/2	F52838
Psilastephanocolporites micus	11	S	RC-0672/52–54	3H/2	9.9/150.3	Q51/0	F52839
Tetracolporate							
Sapotaceoidaepollenites latizonatus	12	A–C	CD-1-1485/38.9–39.0	3D/2	5.2/138.0	V38/0	F52840
S. rotundus	12	D–F	CD-1-779/39.9–40	2E/1	16.4/147.6	J48/0	F52841
Tetracolporites palynius	12	G–I	NND-5077/53.9	2U/2	21.9/129.4	D29/2	F52842
Tetracolporopollenites sp. Milne 1988	12	J, K	NNA-5605/54–55	4I/2	8.3/152.9	S54/1	F52843

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
Hexaporate							
Anacolosidites acutullus	12	L, M	NNA-5605/56–57	5I/2	6.8/162.1	U63/2	F52844
A. acutullus	12	N, O	NND-5077/51.9	3T/1	18.4/158.9	G60/3	F52845
A. luteoides	12	P–R	NNA-5738/59–60	4K/1	6.4/137.4	U38/1	F52846
" "	12	S	CD-1-1360/40.9–41	5D/1	12.8/134.8	N35/0	F52847
" "	12	T, U	CD-1-1360/40.9–41	5D/1	16.0/134.3	K34/2	F52848
Diporate							
Banksieaeidites arcuatus	12	V–X	NNA-5738/64–65	6K/2	6.8/139/6	T40/3	F52494
" "	12	Y, Z	CD-1-779/44.9–50	3E/1	9.0/154.2	R55/0	F52495
Tricolpoid							
Beaupreaidites diversiformis	12	AA–CC	NND-5030/42.2	8R/1	13.4/124.7	M24/4	F52849
" "	13	A–C	NND-5030/37.2	5R/2	10.8/131.3	P31/0	F52850
B. elegansiformis	13	D–F	NNA-5605/56–57	5I/2	9.5/136.0	Q36/4	F52851
B. verrucosus	13	G–I	NNA-5605/56–57	5I/1	15.2/161.7	L63/0	F52852
Triporate							
Bluffopollis scabratus	7	K–M	NNA-5605/60–61	6I/2	12.1/152.6	O53/0	F52787
Haloragacidites harrisii	14	A–C	NNA-5605/56–57	5I/2	9.8/141.7	Q42/0	F52853
" "	14	D	NNA-5605/50–51	3I/2	20.0/142.4	F43/1	F52854
Propylipollis biporous	14	I, J	CD-1-763/72.8–72.9	7/1	9.9/126.0	Q26/3	F52855
P. robustus	14	K–M	RC-0672/44–46	1H/2	12.0/142.4	O43/1	F52856
P. sp. A Milne 1988	14	N, O	NND-5077/53.9	2U/2	16.2/155.6	K56/2	F52857
P. sp. B Milne 1988	14	P–R	NND-5077/51.7	2T/1	20.0/127.5	F27/2	F52858
Proteacidites adenanthoides	14	S–U	NND-5077/51.3	8S/1	22.5/138.6	C39/0	F52859
P. alveolatus	15	A, B	CD-1-1/35.0–35.1	4F/1	9.3/164.0	R65/0	F52860
P. annularis	15	C, D	NNA-5510/78–79	4C/2	10.3/134.0	Q34/1	F52265

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
P. annularis (verrucate)	15	E–G	RC-0672/52–54	3H/2	15.1/135.2	L35/2	F52861
P. beddoesii	15	H	CD-1-1/35.0–35.1	4F/2	4.3/142.2	W42/2	F52862
P. bremerensis	15	I–K	CD-1-481/43.2–43.3	3/2	7.6/147.6	T48/1	F52266
P. carobelindiae	15	L, M	RC-0672/50–52	2H/1	6.1/148.8	U49/4	F52267
" "	15	N, O	NND-5077/51.5	1T/2	15.8/131.1	K31/0	F52863
P. cirritulus	15	P–R	NNA-5605/60–61	6I/2	3.9/142.8	W43/0	F52864
P. confragosus	15	S, T	CD-1-481/42.1–42.2	3F/1	10.7/133.8	P34/3	F52270
P. crassus	16	A–C	OF-1-52/58-60	5B/2	9.8/158.5	Q59/4	F52865
" "	16	D, E	NNA-5738/49–50	2K/2	12.3/155.8	O57/1	F52866
P. cumulus	16	F, G	NND-5077/52.3	5T/2	18.2/125.7	H25/2	F52867
P. cf. *grandis*	16	H, I	NND-5028/39.6	6P/2	10.4/159.5	Q60/2	F52868
P. aff. *Grevillea*	16	J, K	NNA-5605/60–61	6I/2	8.7/155.0	S56/1	F52869
P. aff. *Isopogon*	16	L	RC-0672/52–54	3H/2	7.9/144.8	S45/4	F52870
P. ivanhoensis	16	M	CD-1-481/43.2–43.3	3/2	14.2/131.3	M31/2	F52871
P. kopiensis	17	A, B	NNA-5605/60–61	6I/2	8.8/155.9	R57/3	F52872
P. leightonii	17	E	CD-1-779/65.5–65.6	4E/1	8.8/155.8	R57/3	F52873
P. cf. *leightonii*	17	C, D	NNA-5510/74–75	3C/2	7.3/149.0	T50/1	F52874
P. cf. *microverrucatus*	17	F, G	NNA-5510/74–75	3C/2	7.1/148.5	T49/0	F52875
P. nasus	17	H–J	NND-5077/53.7	1U/2	11.5/141.4	O42/0	F52876
P. nasus (small)	17	K–N	CD-1-779/65.5–65.6	4E/1	5.6/162.9	V64/0	F52877
P. cf. *nexinus*	18	A–C	CD-1-779/65.5–65.6	4E/1	14.6/139.6	L40/3	F52878
P. cf. *nitidus*	18	D, E	RC-0672/50–52	2H/1	7.8/152.1	S53/3	F52879
P. 'notredamus'	18	F, G	CD-1-481/38.9–39	2F/2	6.8/148.2	T49/3	F52880
P. obscurus	18	H, I	NND-5077/53.7	1U/1	13.5/144.3	N45/1	F52881
" "	18	J, K	CD-1-1485/40.6–40.7	4A/2	8.5/129.7	R29/4	F52882

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
" "	18	L, M	CD-1-779/44.9–45	3E/2	13.7/147.8	M48/4	F52883
P. cf. *ornatus*	19	A–C	CD-1-779/39.9–40	2E/1	16.9/152.7	J53/2	F52884
P. pachypolus	19	D–F	CD-1-779/44.9–45	3E/1	14.3/150.2	M51/1	F52885
P. pseudomoides	19	G, H	CD-1-779/71.2–71.3	5E/1	6.0/125.8	U26/1	F52886
P. cf. *pseudomoides* sp. 1	19	I, J	CD-1-409/39.9–40	7D/1	11.0/131.9	P32/0	F52887
P. cf. *pseudomoides* sp. 3	19	K	OF-1-52/58-60	5B/2	11.0/148.6	P49/0	F52888
P. punctiporus	19	L, M	NND-5077/51.1	7S/2	11.6/124.4	O24/0	F52889
P. rectomarginis	19	N, O	CD-1-779/65.5–65.6	4E/1	16.4/156.8	J58/3	F52890
P. rectus	19	P, Q	CD-1-409/39.9–40	7D/1	11.9/158.7	O60/3	F52891
P. reticulatus	19	R, S	CD-1-481/38.9–39	2F/2	22.8/137.9	C38/2	F52892
P. cf. *reticulatus*	20	A, B	NNA-5738/49–50	2K/2	9.4/138.3	R38/2	F52893
" "	20	C, D	RC-0672/56–58	4H/2	4.2/137.1	W37/0	F52894
P. rynthius	20	E, F	NND-5077/53.7	1U/1	22.1/142.3	D43/1	F52895
" "	20	G, H	NND-5028/39.6	6P/1	13.2/129.6	N30/1	F52896
" "	20	I, J	RC-0672/56–58	4H/1	12.0/157.0	O58/0	F52897
P. scitus	20	K, L	CD-1-1/67–67.1	8/2	7.2/141.6	T42/0	F52898
P. cf. *simplex*	20	M, N	CD-1-763/72.8–72.9	7/1	14.0/149.9	M50/2	F52899
P. cf. *stipplatus*	20	O–Q	RC-0672/52–54	3H/1	11.9/155.2	O56/0	F52900
P. subscabratus	20	R	CD-1-779/44.9–45	3E/1	2.0/150.5	V51/4	F52901
P. symphyonemoides	21	A, B	NNA-5605/46–47	1I/2	21.7/141.4	D42/0	F52902
P. tenuiexinus	21	C–E	NND-5077/51.1	7S/2	15.0/135.4	L35/2	F52903
P. tuberculatus	21	F–H	NND-5077/52.1	4T/1	15.4/129.0	K29/3	F52904
P. tuberculiformis	21	I, J	NNA-5605/54–55	4I/1	15.1/147.6	L48/0	F52905
Santalumidites cainozoicus	14	E, F	NNA-5510/43–44	1M/1	6.5/139.5	U40/1	F52906
" "	14	G, H	CD-1-779/44.9–45	3E/2	18.0/127.0	H27/0	F52907

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
Triporopollenites ambiguus	21	K, L	NNA-5738/49–50	2K/1	14.3/153.9	M55/1	F52908
T. delicatus	21	M, N	NND-5028/42.2	1Q/1	12.4/146.3	O47/1	F52909
T. vargus	21	O–Q	OF-1-52/58-60	5B/2	10.0/150.1	Q51/0	F52910
Stephanoporate							
Malvacipollis diversus	22	A–C	NNA-5606/46–47	2I/1	14.1/134.8	M35/0	F52911
M. spinyspora	22	D, E	RC-0277/70–72	7F/2	7.1/150.7	T51/0	F52912
M. subtilis	22	F, G	CD-1-1/40–40.1	1A/1	14.8/145.3	L46/0	F52913
Periporate							
Periporopollenites demarcatus	22	H–J	CD-1-779/44.9–45	3E/2	17.3/132.8	H33/3	F52914
" "	22	K	NNA-5605/50–51	3I/2	17.9/154.7	H55/2	F52915
Tetrad							
Ericipites scabratus	22	L, M	NNA-5605/50–51	3I/2	12.7/152.0	N53/3	F52916
" "	22	N, O	NNA-5605/56–57	5I/2	11.3/130.4	P30/2	F51917

APPENDIX 5. Register of illustrated fossil specimens of new species.

Authors listed in Appendix 9.

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
Cryptogam Spores							
Cyathidites sp.	23	A–C	RC-0672/52–54	3H/1	14.4/127.4	L27/4	F52918
Rugulatisporites sp.	23	D	NND-5077/51.1	3T/2	11.3/144.4	P45/0	F52919
Spore sp. A	23	E	RC-0672/56–58	4H/1	16.0/144.6	K45/0	F52920
Spore sp. B	23	F	NND-5077/53.7	1U/2	8.6/147.7	S48/2	F52921
Angiosperms							
Tricolpate							
Tricolpites discoides	23	G, H	OF-1-52/58-60	5B/2	18.0/129.9	H30/1	F52922
" "	23	I	RC-0672/52–54	3H/1	2.3/138.6	Y39/0	F52923
Tricolpites occultum	23	J–L	NNA-5510/43–44	1M/1	2.2/127.5	Y27/2	F52924
" "	23	M	NND-5028/45	5Q/2	14.9/131.7	L32/1	F52925
Tricolpites reticularis	23	N, O	CD-1-1360/39.4–39.5	5A/1	5.3/146.0	V46/2	F52926
" "	23	P	NND-5030/37.2	5R/2	3.4/138.0	X38/2	F52927
" "	23	Q, R	CD-1-409/39.9–40	7D/1	15.7/126.4	K26/0	F52928
Tricolpites sp. A	24	A	CD-1-481/42.1–42.2	3F/1	4.1/146.3	W47/3	F52929
" "	24	B	NND-5028/43.6	3Q/1	5.2/148.3	V49/0	F52930
Tricolpites sp. B	24	C, D	NND-5077/53.7	1U/2	5.2/157.6	V58/4	F52931
Tricolporate							
Rhoipites oralongii	24	E–G	RC-0672/60–62	5H/1	15.2/152.9	L54/1	F52932
Rhoipites orbiculatus	24	H–K	CD-1-1/67–67.1	8/2	10.2/152.9	Q53/2	F52933
" "	24	L–N	NND-5030/51.3	4S/1	11.7/138.8	O39/0	F52934
Rhoipites sp. A	24	R–U	RC-0672/56–58	4H/1	11.4/145.4	P46/1	F52935
Tricolporites sp. B	24	V–X	RC-0277/70–72	7F/1	12.7/122.7	N22/4	F52936
Tricolporites sp. A	24	Z, Y	CD-1-409/39.9–40	7D/1	17.5/152.5	J53/0	F52937

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
Syncolporate							
Myrtaceidites corymbioides	24	U, V	NNA-5025/72–73	7B/2	4.3/132.1	W32/0	F52258
Triporate							
Proteacidites ambassadatus	25	A–C	CD-1-409/34.7–34.8	1B/2	4.9/151.2	V52/3	F52938
" "	25	D–F	CD-1-763/45.2–45.3	4/3	9.8/149.4	Q50/0	F52939
Proteacidites colubrimodus	25	G–I	NNA-5605/56–57	5I/2	2.2/126.0	Y26/0	F52940
" "	25	J–L	CD-1-779/65.5–65.6	4E/1	10.2/126.7	Q26/2	F52941
" "	26	A–C	CD-1-779/71.2–71.3	5E/2	22.6/160.1	C61/0	F52942
Proteacidites crochetaria	26	D–G	CD-1-779/39.9–40	2E/1	2.1/135.0	Y35/0	F52943
Proteacidites microspinosus	26	H–J	CD-1-779/44.9–45	3E/1	16.2/129.9	K30/1	F52944
" "	26	K, L	CD-1-481/40.9–41	2/1	4.8/126.3	V26/4	F52945
Proteacidites narnooensis	26	M, N	NND-5077/51.1	3T/1	16.0/138.9	K39/0	F52946
" "	26	O, P	CD-1-1360/39.4–39.5	5A/1	4.5/131.8	W32/1	F52947
Proteacidites polygonalis	26	Q, R	CD-1-481/43.2–43.3	3/2	10.2/145.7	Q46/0	F52948
" "	26	S, T	CD-1-763/72.8–72.9	7/1	5.4/140.2	V40/2	F52949
Proteacidites protrudens	27	A–C	OF-1-52/58-60	5B/2	12.9/154.8	N55/4	F52950
" "	27	D–F	CD-1-779/39.9–40	2E/1	8.7/140.4	R41/3	F52951
Proteacidites rickmanii	27	G–J	NND-5077/53.9	2U/2	23.2/148.3	B49/3	F52952
Proteacidites tesselaria	28	A–C	NND-5077/53.7	1U/1	14.0/139.0	M39/0	F52953
" "	28	D, E	NND-5077/51.7	2T/2	8.9/159.9	R61/3	F52954
Proteacidites vaga	28	F–I	CD-1-409/39.9–40	7D/1	11.4/142.8	P43/0	F52955
" "	28	J, K	CD-1-409/34.7–34.8	1B/2	10.9/154.9	P56/3	F52956
Proteacidites sp. A	28	L, M	CD-1-763/72.8–72.9	7/1	7.7/134.8	S35/3	F52957
Proteacidites sp. B	28	N, O	CD-1-1/40–40.1	1A/1	4.8/154.6	V55/4	F52958
Proteacidites sp. C	28	P, Q	CD-1-1/40–40.1	1A/1	4.8/125.8	V25/4	F52959

Species	Plate	Figure	Drill Hole/Depth (m)	Slide No.	OLYMPUS Co-ord.	England Finder	Repository
Proteacidites sp. D	28	R, S	CD-1-481/42.1–42.2	3F/1	7.5/140.9	T41/2	F52960
Proteacidites sp. E	28	T–W	NND-5077/51.1	3T/1	20.3/146.6	E47/4	F52961
Proteacidites sp. F	29	A–C	CD-1-409/39.9–40	7D/1	13.9/142.3	M43/3	F52962
Proteacidites sp. G	29	D–F	CD-1-1/35.0–35.1	4F/1	9.2/141.4	R42/1	F52963
Proteacidites sp. H	29	G, H	NND-5030/51.3	4S/1	7.5/142.2	T43/1	F52964
Proteacidites sp. I	29	I–K	NND-5077/52.1	4T/1	19.6/133.9	F34/0	F52965

APPENDIX 6. Photographic plates

Photomicrographs of species discussed in Chapter 7. All photomicrographs were taken at x 1000 using an Olympus P71 digital camera mounted to an OLYMPUS – BX51 transmitted light biological microscope. Photomicrographs of previously described species (Chapter 5) are arranged first, as ordered in the systematics, followed by new species.

APPENDIX 6A. Photomicrographs of previously described species

PLATE 1

Photomicrographs of cryptogam spores. All scale bars 10µm.

Figures

A, B	*Baculatisporites comaumensis*, same grain
C, D	*Cibotiidites tuberculatus*, same grain
E, F	*Cyathidites major*/*minor*, same grain
G	*Dictyophyllidites equiexinus*
H	*Gleicheniidites circinidites*
I–K	*Laevigatosporites ovatus*, I, J same grain
L–N	*Latrobosporites marginis*, same grain

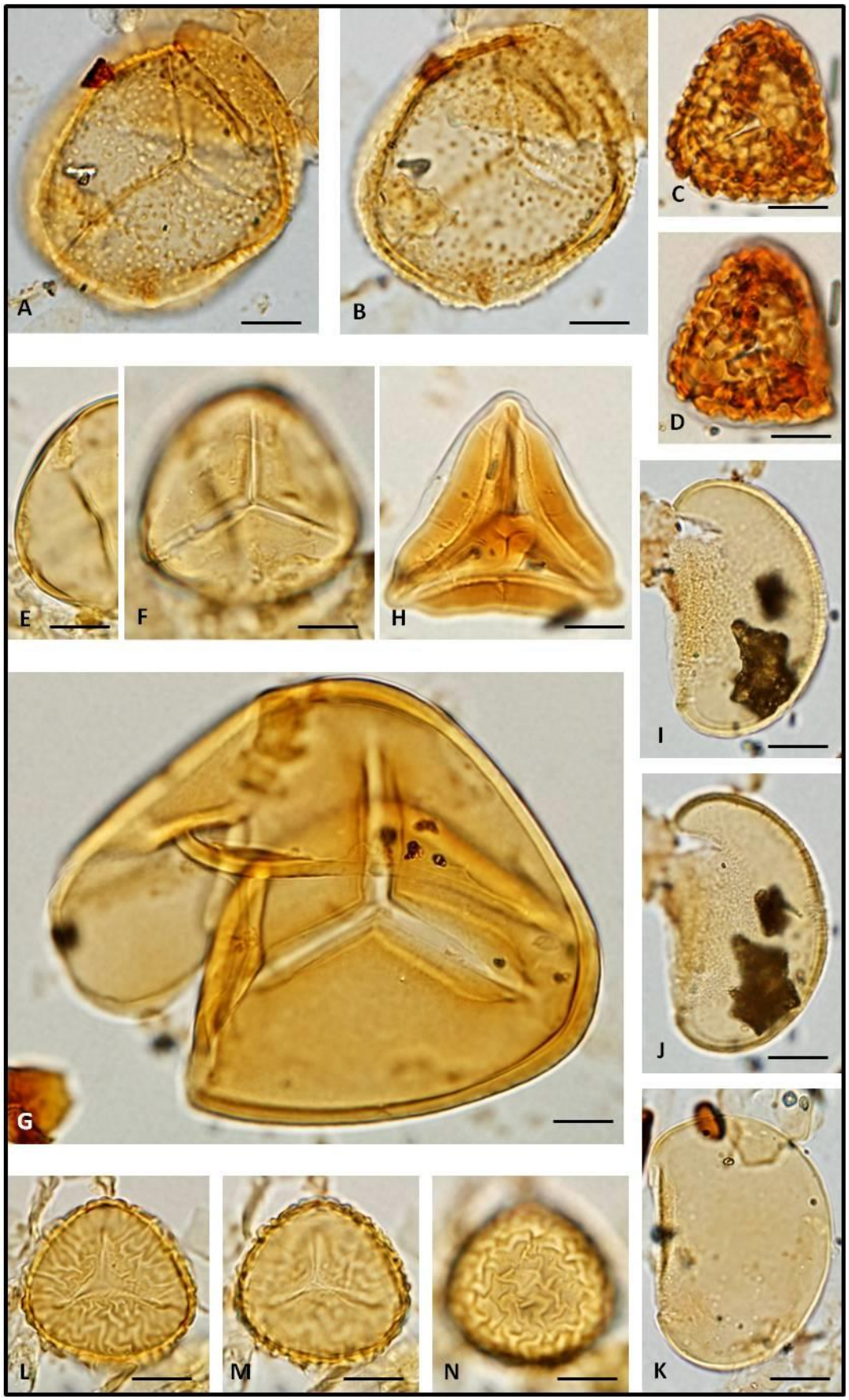

A
B
C
D
E
F
H
I
G
J
L
M
N
K

PLATE 2

Photomicrographs of cryptogam spores. All scale bars 10µm.

Figures

A, B	*Latrobosporites ohaiensis*, same grain
C, D	*Monolites* cf. *alveolatus*, same grain
E, F	*Neoraistrickia* cf. *levidensis*, same grain
G, H	*Peromonolites vellosus*, same grain
I, J	*Punctatosporites* cf. *scabratus*, same grain
K, L	*Verrucatosporites speciosus*, same grain

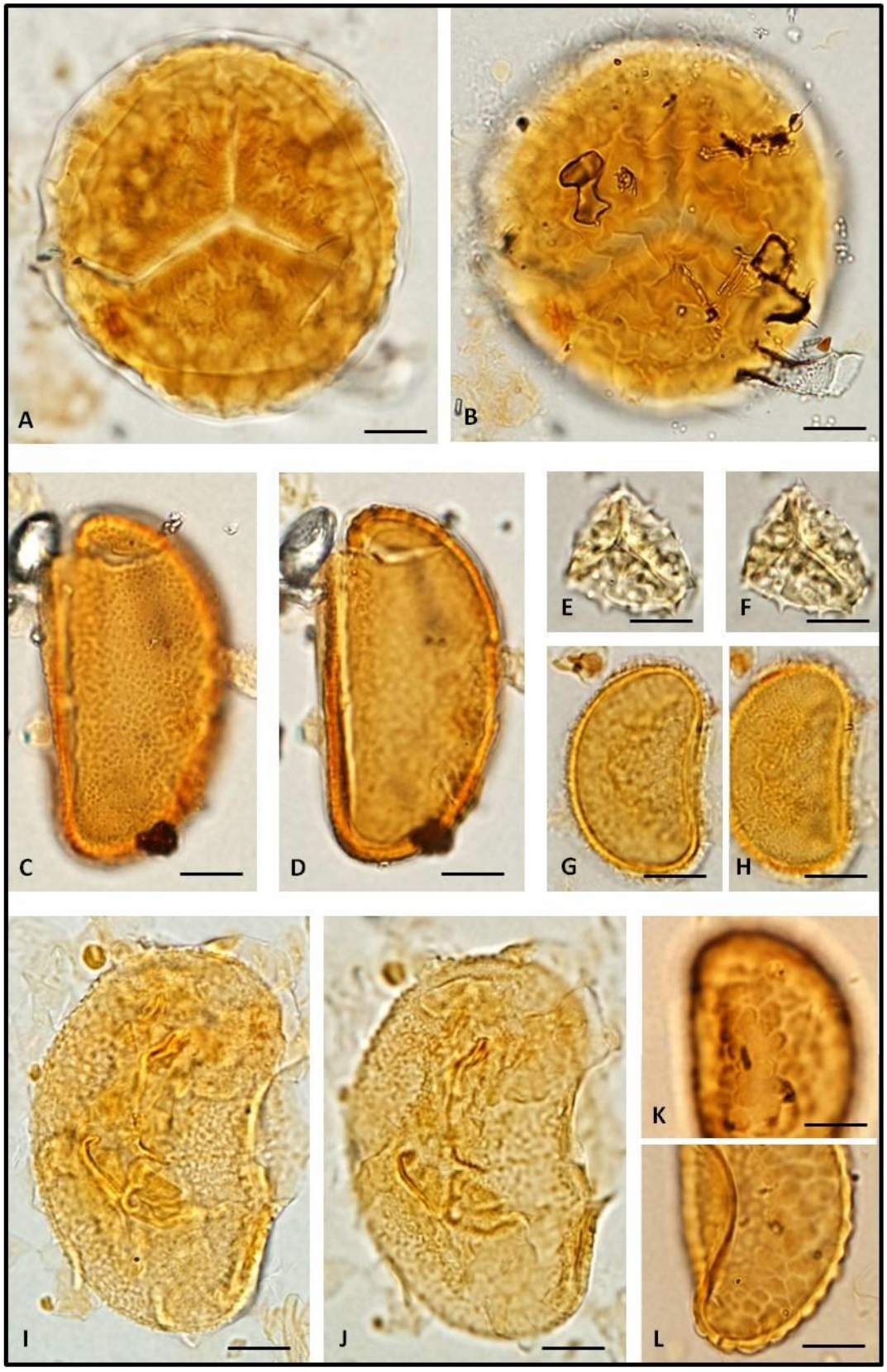

A
B
C
D
E
F
G
H
I
J
K
L

PLATE 3

Photomicrographs of cryptogam spores (A–F) and gymnosperm pollen (G, H). All scale bars 10µm.

Figures

A, B	*Verrucosisporites cristatus*, same grain
C, D	*Verrucosisporites kopukuensis*, same grain
E, F	*Rugulatisporites micraulaxis*, same grain
G, H	*Lygistepollenites florinii*, same grain

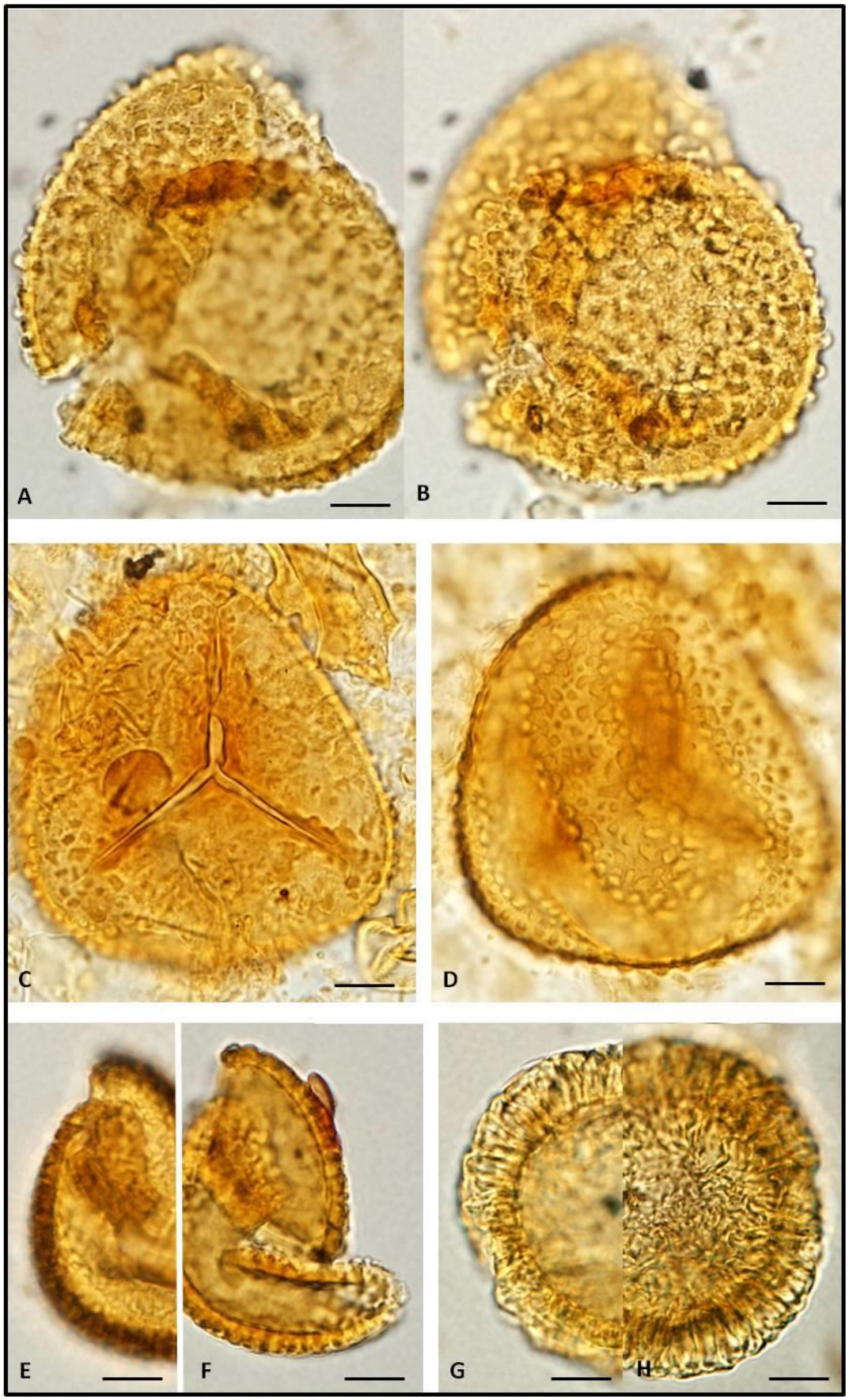

A
B
C
D
E
F
G
H

PLATE 4

Photomicrographs of gymnosperm pollen. All scale bars 10µm.

Figures

A, B	*Lygistepollenites florinii*, same grain
C–F	*Parvisaccites catastus*, C, D same grain, E, F, same grain
G–J	*Phyllocladidites mawsonii*, G, H same grain, I, J same grain
K–M	*Podocarpidites ellipticus*, K, L same grain
N, O	*Podocarpidites puteus*, same grain
P, Q	*Dacrycarpites australiensis*, same grain
R, S	*Trichotomosulcites subgranulatus*, same grain

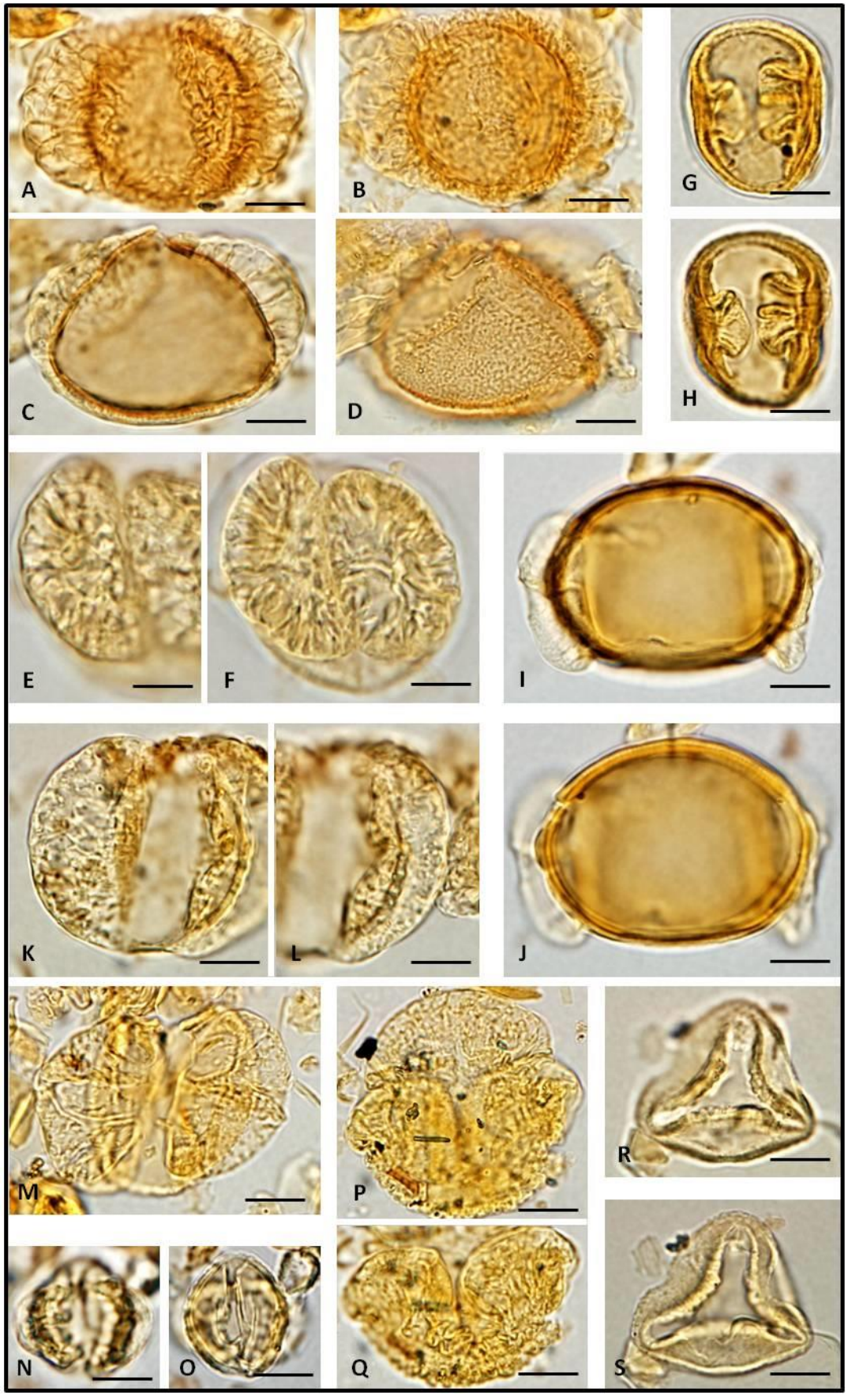

A
B
G
C
D
H
E
F
I
K
L
J
M
P
R
N
O
Q
S

PLATE 5

Photomicrographs of monocolpate, monosulcate and tricolpate angiosperm pollen.
All scale bars 10μm.

Figures

A, B	*Aglaoreidia qualumis*, same grain
C, D	*Clavatipollenites ascarinoides*, same grain
E, F	*Arecipites subverrucatus*, same grain
G–I	*Arecipites waitakiensis*, same grain
J–L	*Liliacidites aviemorensis*, same grain
M, N	*Liliacidites variegatus*, same grain
O–Q	*Sparganiaceaepollenites barungensis*, same grain
R, S	*Tricolpites confessus*, same grain
T–V	*Perfotricolpites digitatus*, same grain
W–BB	*Tricolpites incisus*, W, X same grain, Z–AB same grain

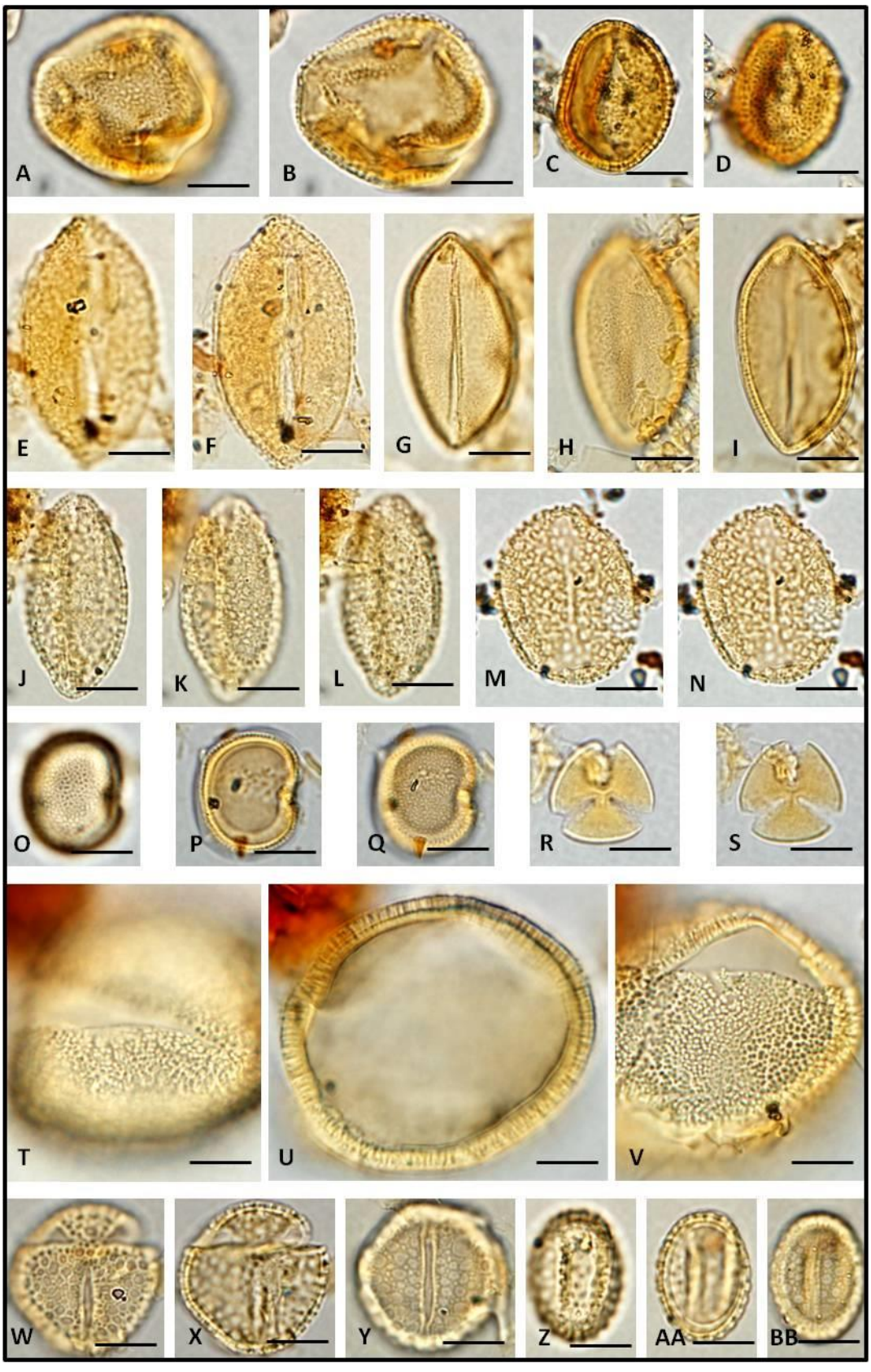

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB

PLATE 6

Photomicrographs of tricolpate angiosperm pollen. All scale bars 10µm.

Figures

A, B	*Tricolpites* cf. *lilliei*, same grain
C–E	*Tricolpites perlongicolpus*, same grain
F	*Tricolpites phillipsii*, same grain
G, H	*Tricolpites* cf. *reticulatus*, same grain
I–K	*Tricolpites secarius*, same grain
L–N	*Tricolpites simatus*, same grain
O, P	*Tricolpites thomasii*, same grain
Q, R	*Tricolpites thomasii* (syncolpate), same grain

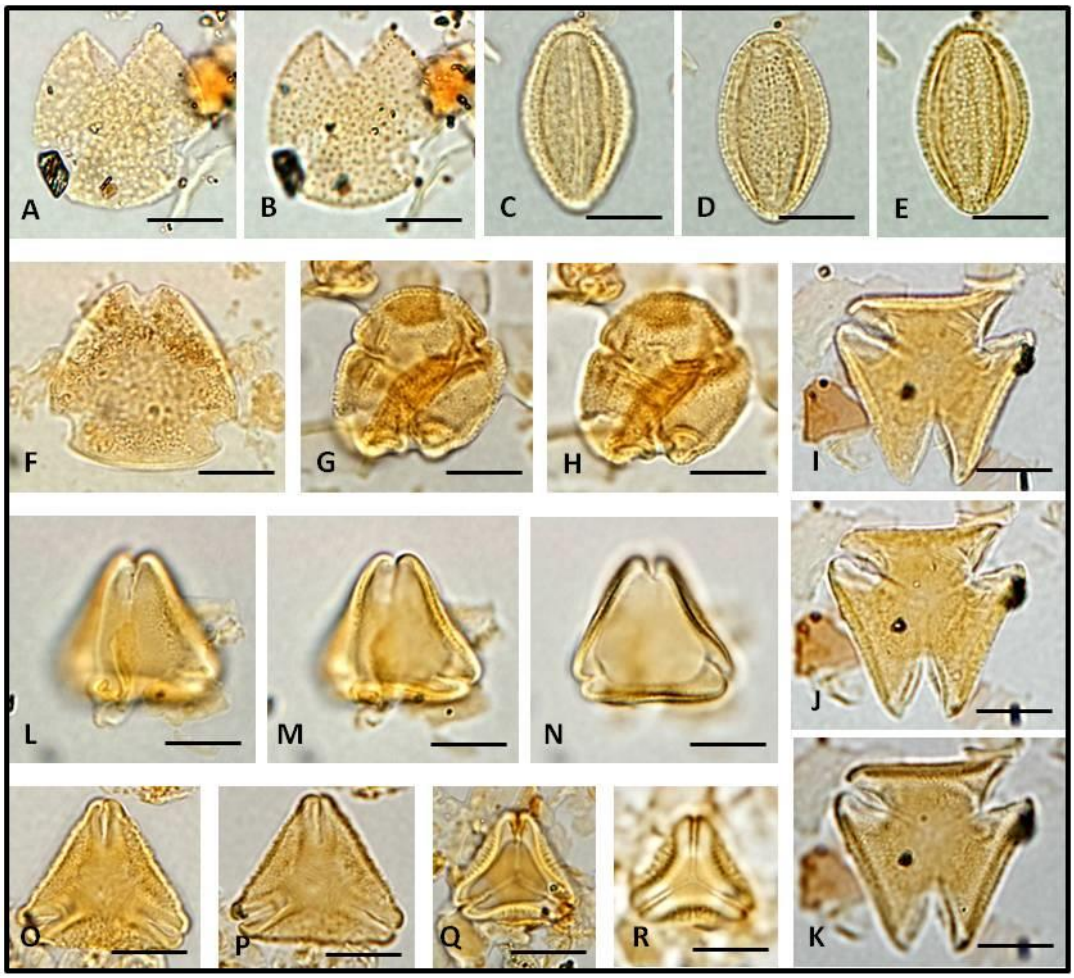

A
B
C
D
E
F
G
H
I
L
M
N
J
O
P
Q
R
K

PLATE 7

Photomicrographs of tricolporate angiosperm pollen. All scale bars 10µm.

Figures

A–E	*Ailanthipites mulleri*, A, B same grain, C–E same grain
F–J	*Ailanthipites paenestriatus*, F, G same grain, H–J same grain
K–M	*Bluffopollis scabratus*, same grain
N–R	*Ilexpollenites anguloclavatus*, N, O same grain, P, Q same grain
S, T	*Ilexpollenites megagemmatus*, same grain
U, V	*Ilexpollenites verrucatus*, same grain
W–BB	*Rhoipites alveolatus*, W, X same grain, Z–BB same grain
CC, DD	*Rhoipites angurium*, same grain

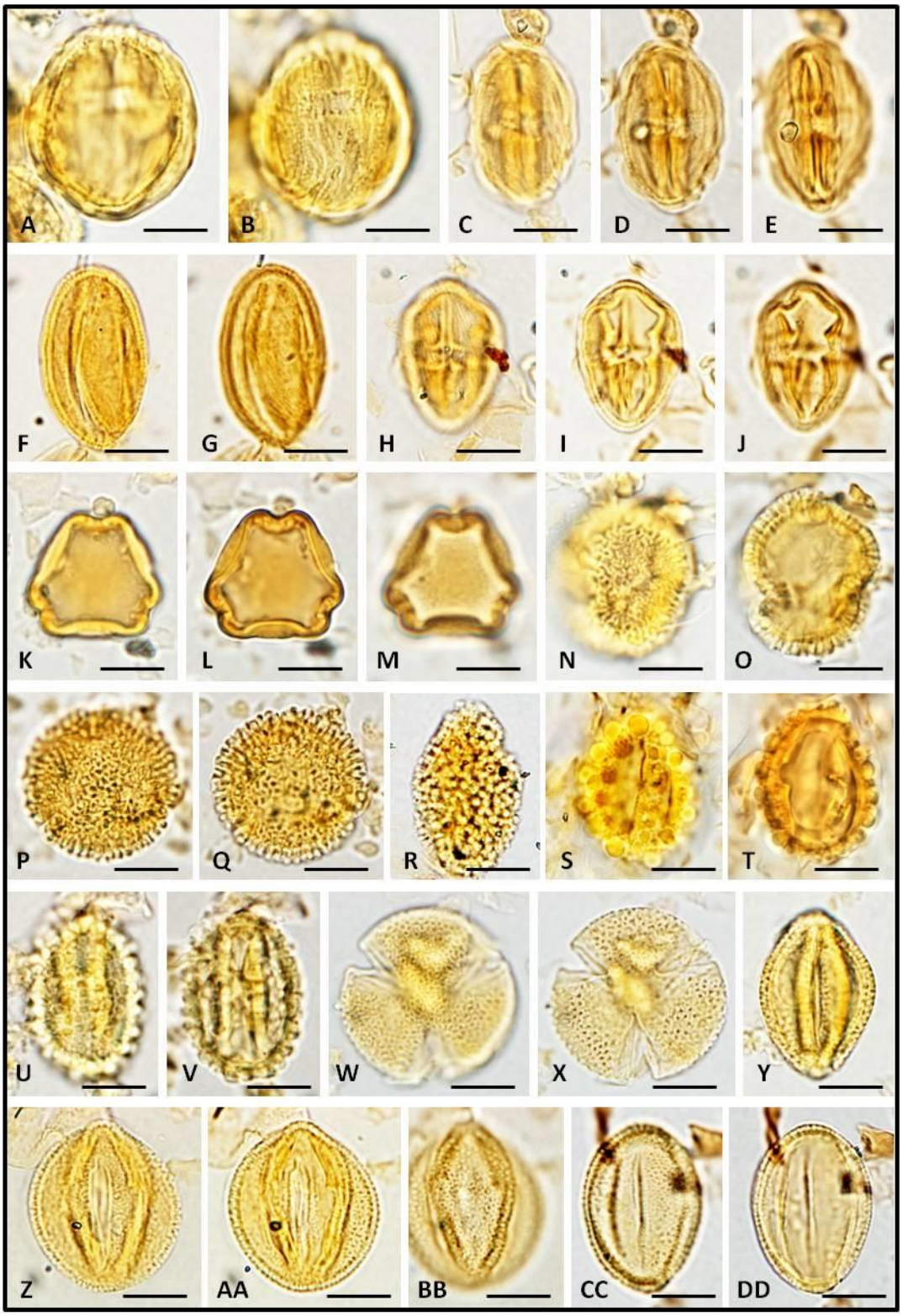

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB
CC
DD

PLATE 8

Photomicrographs of tricolporate angiosperm pollen. All scale bars 10µm.

Figures

A–D	*Rhoipites aralioides*, same grain
E–I	*Rhoipites cissus*, E, F same grain, G–I same grain
J, K	*Rhoipites fragilis*, same grain
L–N	*Rhoipites hawkdunensis*, same grain
O–S	*Rhoipites goulburnensis*, O, P same grain, Q–S same grain
T–Y	*Rhoipites microreticulatus*, T–V same grain, W–Y same grain
Z–BB	*Rhoipites ivanhoensis*, same grain
CC–FF	*Rhoipites minutiformis*, CC, DD same grain, EE, FF same grain
GG–II	*Rhoipites muehlenbeckiaformis*, same grain
JJ, KK	*Rhoipites rotundiformis*, same grain

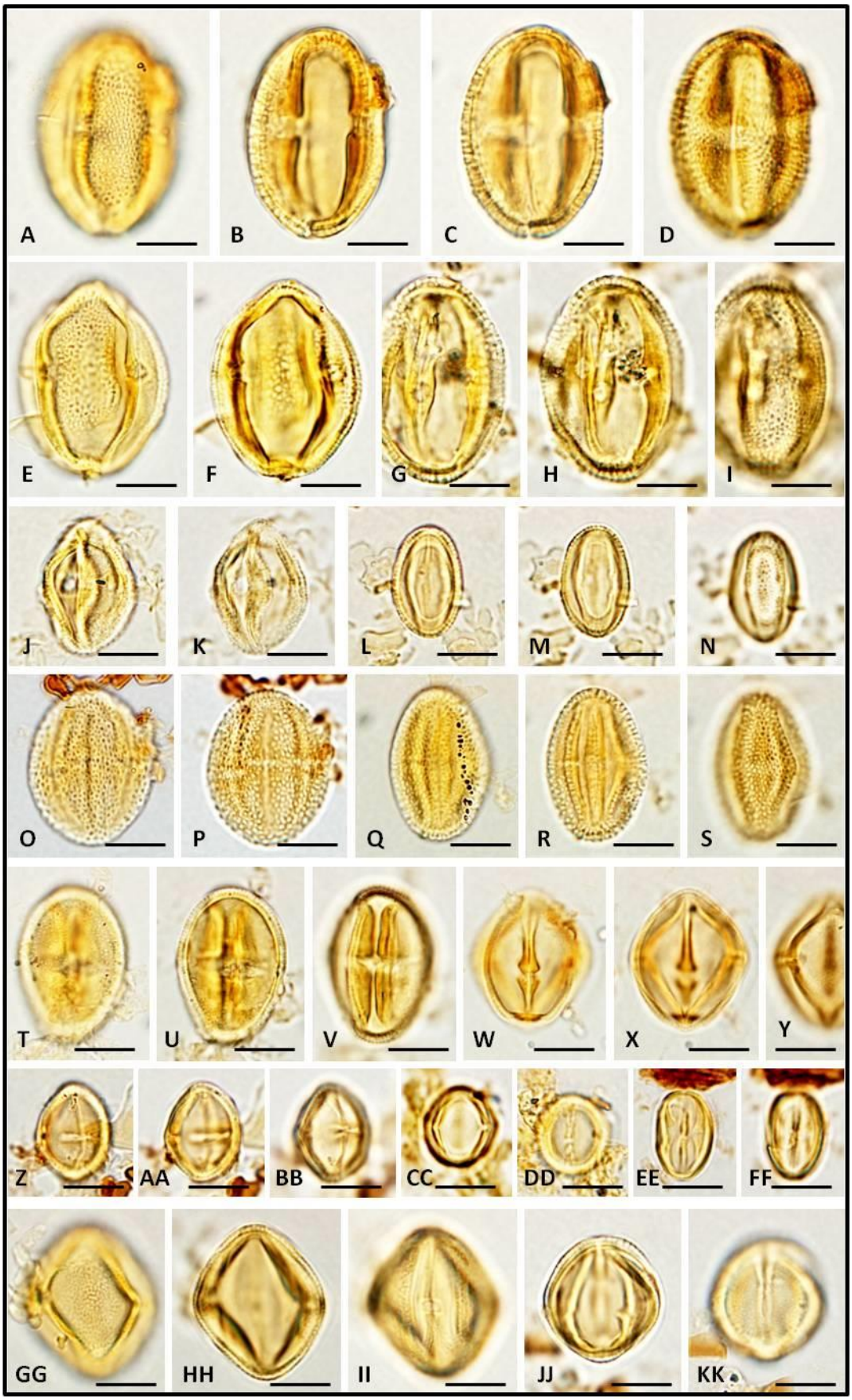

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB
CC
DD
EE
FF
GG
HH
II
JJ
KK

PLATE 9

Photomicrographs of tricolporate angiosperm pollen. All scale bars 10µm.

Figures

A–C	*Schizocolpus marlinensis*, same grain
D–H	*Tricolporites adelaidensis*, D–F same grain, G–H same grain
I–K	*Tricolporites* cf. *cooksonii*, same grain
L–M	*Tricolporites leuros*, same grain
N, O	*Tricolporites pelarganoides*, same grain
P–S	*Tricolporites prolata*, P, Q same grain, R, S, same grain
T	*Rhoipites sphaerica*
U, V	*Tricolporites scabratus*, same grain
W	*Tricolporites valvatus*

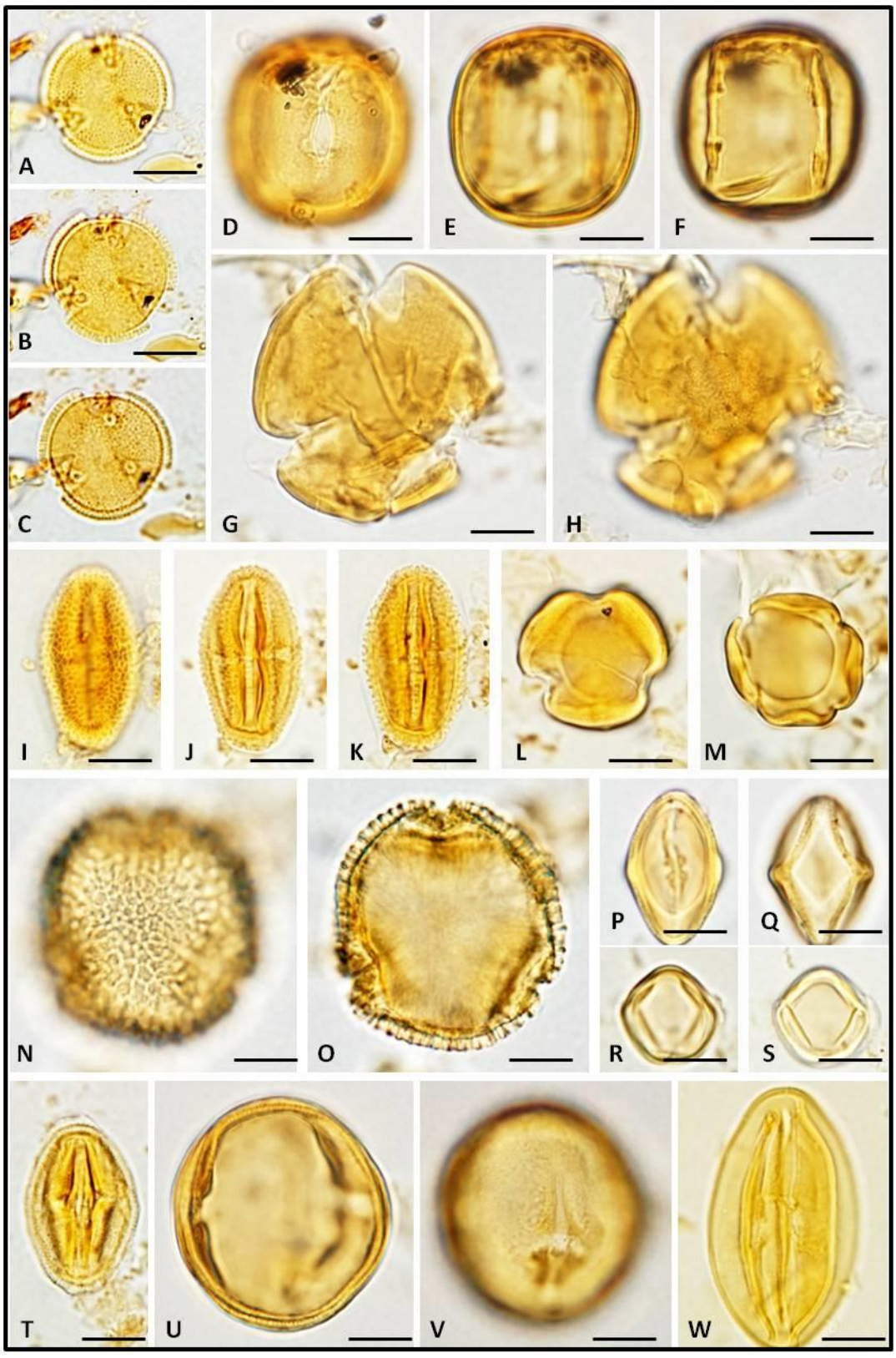

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W

PLATE 10

Photomicrographs of syncolpate, syncolporate and polycolpate angiosperm pollen. All scale bars 10μm.

Figures

A–D	*Cupanieidites major*, A, B same grain, C, D same grain
E, F	*Cupanieidites orthoteichus* same grain
G–J	*Cupanieidites reticularis*, H–J same grain
K, L	*Gothanipollis bassensis*, same grain
M–O	*Myrtaceidites eucalyptoides*, same grain
P, Q	*Myrtaceidites mesonesus/parvus*, same grain
R–W	*Nothofagidites brachyspinulosus/incrassatus*, R–T same grain, U–W same grain
X–Z	*Nothofagidites emarcidus/heterus*, X, Y same grain

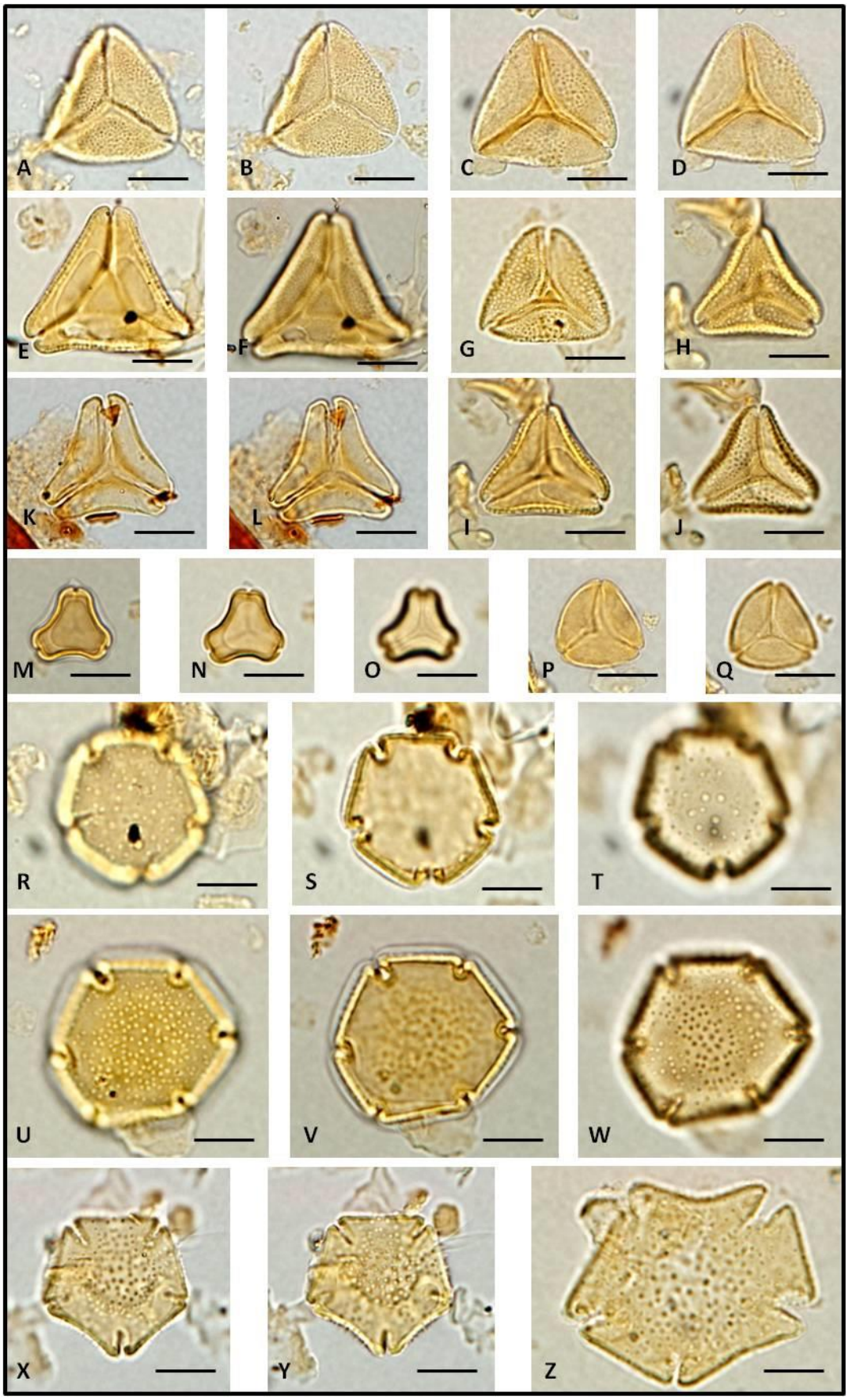

A
B
C
D
E
F
G
H
K
L
I
J
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z

PLATE 11

Photomicrographs of polycolpate and polycolporate angiosperm pollen. All scale bars 10µm.

Figures

A	*Nothofagidites emarcidus/heterus*
B–G	*Nothofagidites falcatus*, B–D same grain, E–G same grain
H, I	*Nothofagidites longispinosus*, same grain
J–L	*Nothofagidites senectus,* same grain
M–O	*Nothofagidites spinosus,* same grain
P–R	*Nothofagidites vansteenisii*, same grain
S	*Psilastephanocolporites micus*
T–W	*Polycolporopollenites esobalteus*, same grain

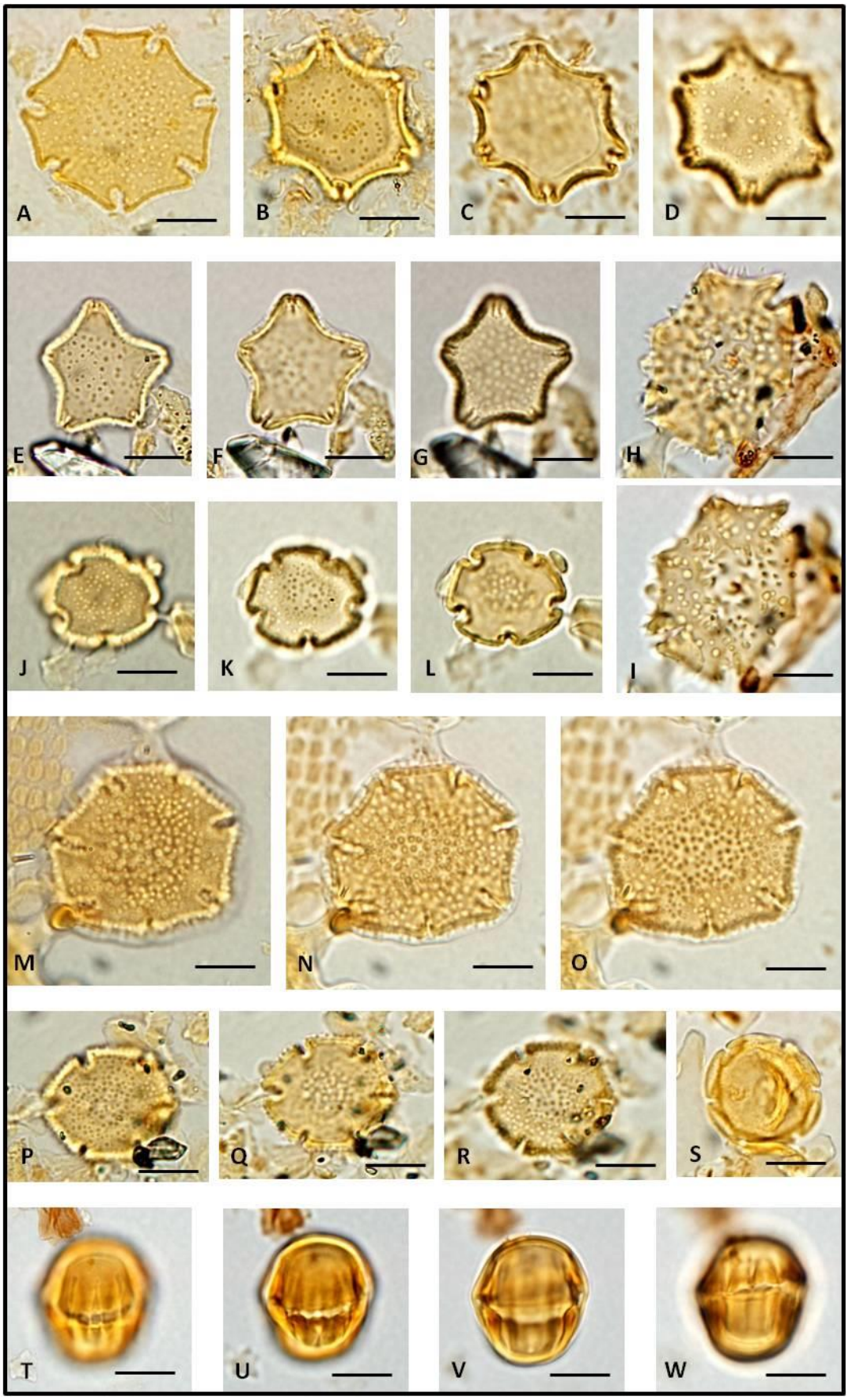

A
B
C
D
E
F
G
H
J
K
L
I
M
N
O
P
Q
R
S
T
U
V
W

PLATE 12

Photomicrographs of tetracolporate, hexaporate, diporate and tricolpoid angiosperm pollen. All scale bars 10µm.

Figures

A–C	*Sapotaceoidaepollenites latizonatus*, same grain
D–F	*Sapotaceoidaepollenites rotundus*, same grain
G–I	*Tetracolporites palynius*, same grain
J, K	*Tetracolporopollenites* sp. Milne 1988, same grain
L–O	*Anacolosidites acutullus*, L, M same grain, N, O same grain
P–U	*Anacolosidites luteoides*, P–R same grain, T, U same grain
V–Z	*Banksieaeidites arcuatus*, V–X same grain, Y, Z same grain
AA–CC	*Beaupreaidites diversiformis*, same grain

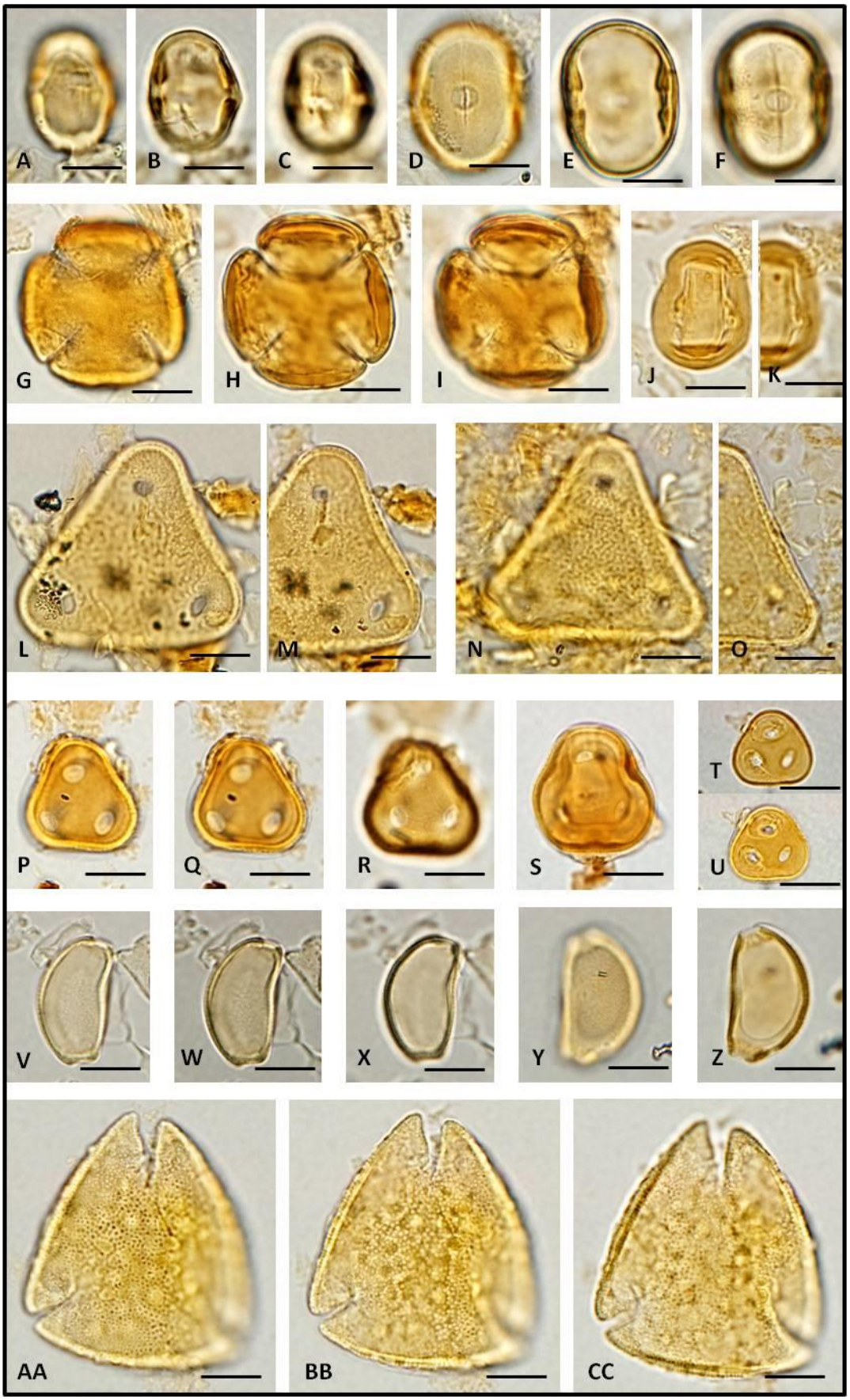

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB
CC

PLATE 13

Photomicrographs of tricolpoid angiosperm pollen. All scale bars 10µm.

Figures

A–C *Beaupreaidites diversiformis*, same grain

D–F *Beaupreaidites elegansiformis*, same grain

G–I *Beaupreaidites verrucosus*, same grain

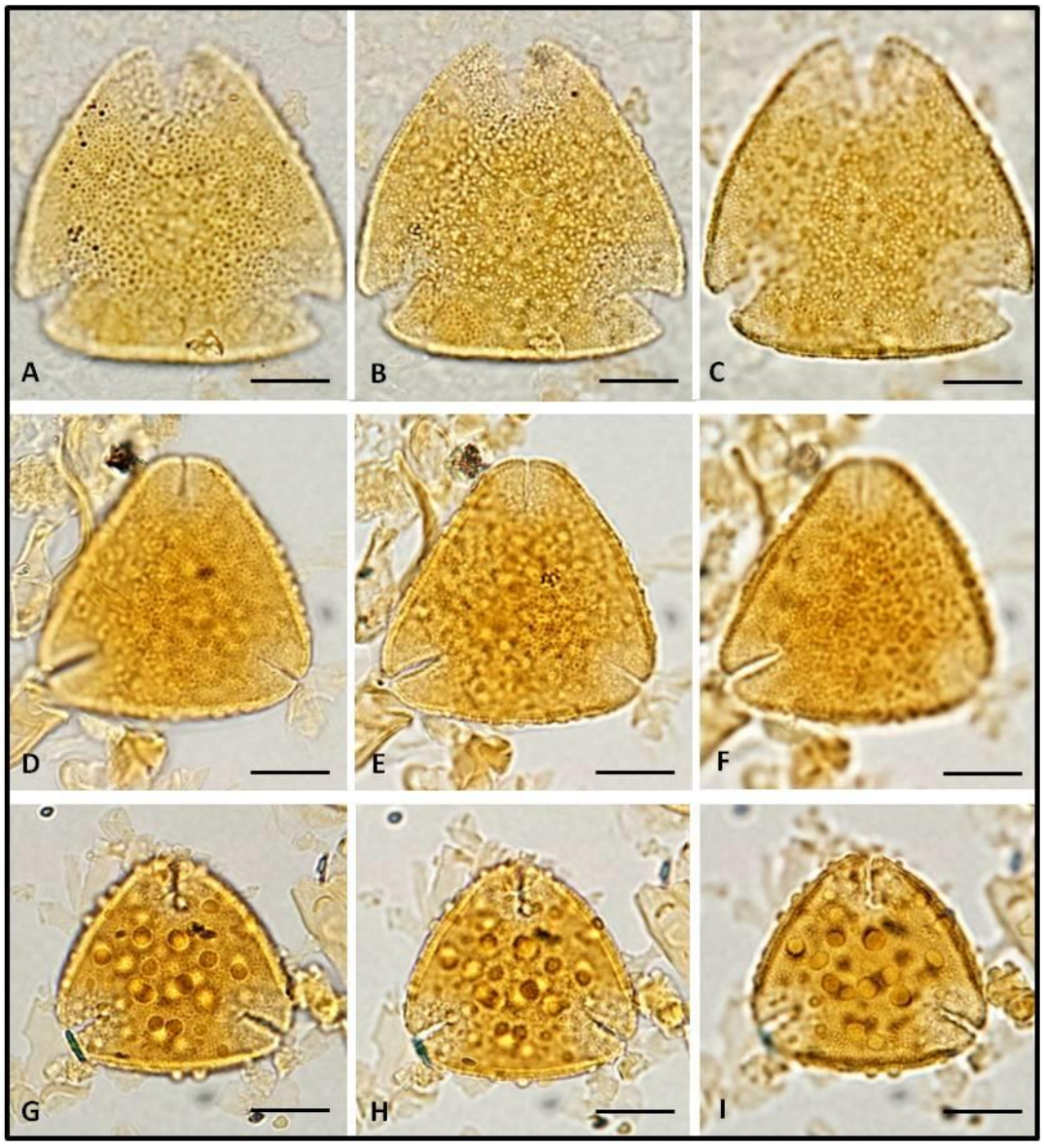

A
B
C
D
E
F
G
H
I

PLATE 14

Photomicrographs of triporate angiosperm pollen. All scale bars 10µm.

Figures

A–D	*Haloragacidites harrisii,* A–C same grain
E–H	*Santalumidites cainozoicus*, E, F same grain, G, H same grain
I, J	*Propylipollis biporus*, same grain
K–M	*Propylipollis robustus*, same grain
N, O	*Propylipollis* sp. A Milne 1988, same grain
P–R	*Propylipollis* sp. B Milne 1988, same grain
S–U	*Proteacidites adenanthoides*, same grain

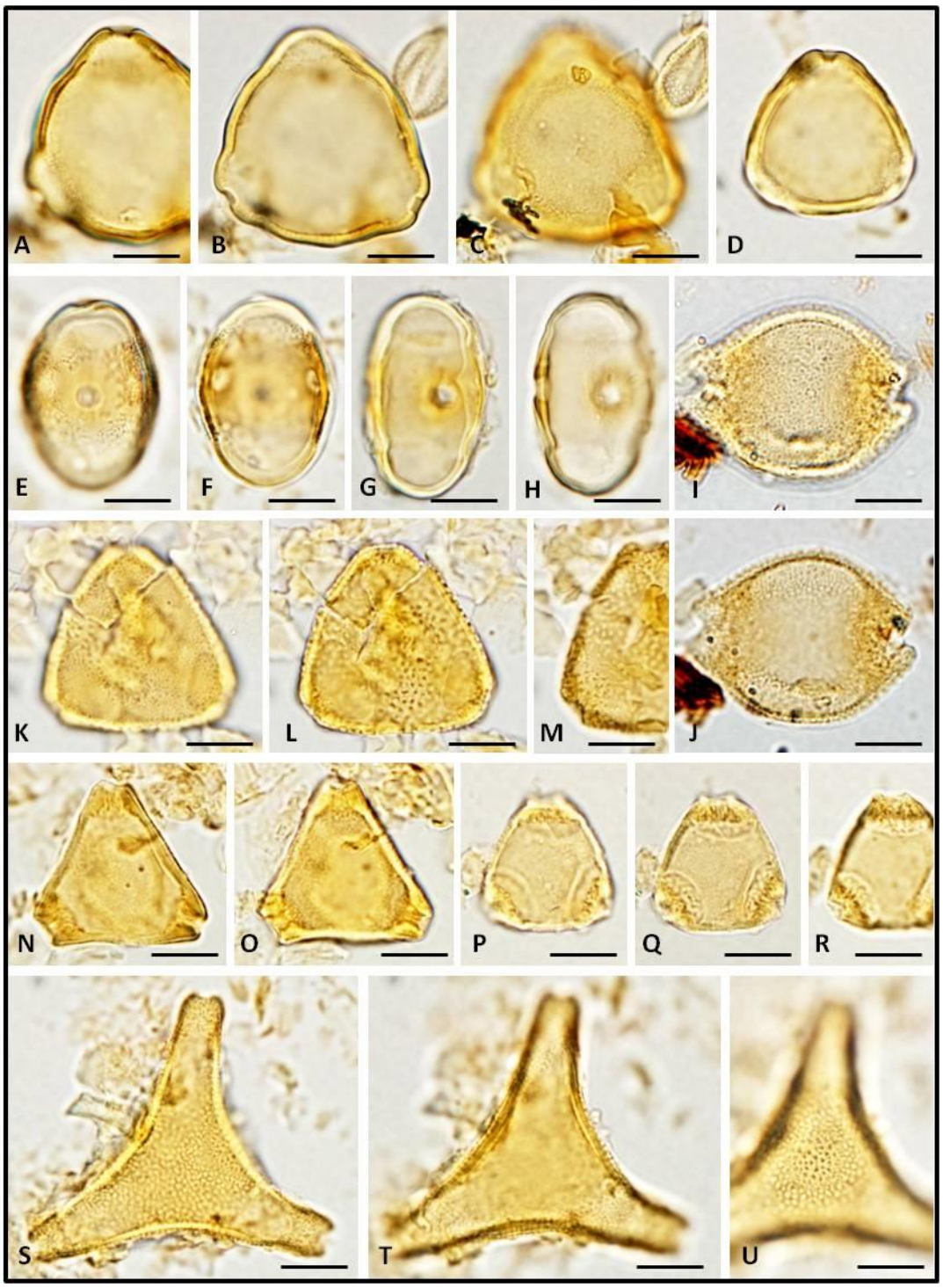

A
B
C
D
E
F
G
H
I
K
L
M
J
N
O
P
Q
R
S
T
U

PLATE 15

Photomicrographs of triporate angiosperm pollen. All scale bars 10µm.

Figures

A, B	*Proteacidites alveolatus*, same grain
C, D	*Proteacidites annularis*, same grain
E–G	*Proteacidites annularis* (verrucate), same grain
H	*Proteacidites beddoesii*
I–K	*Proteacidites bremerensis*, same grain
L–O	*Proteacidites carobelindiae*, L, M same grain, N, O same grain
P–R	*Proteacidites cirritulus*, same grain
S, T	*Proteacidites confragosus*, same grain

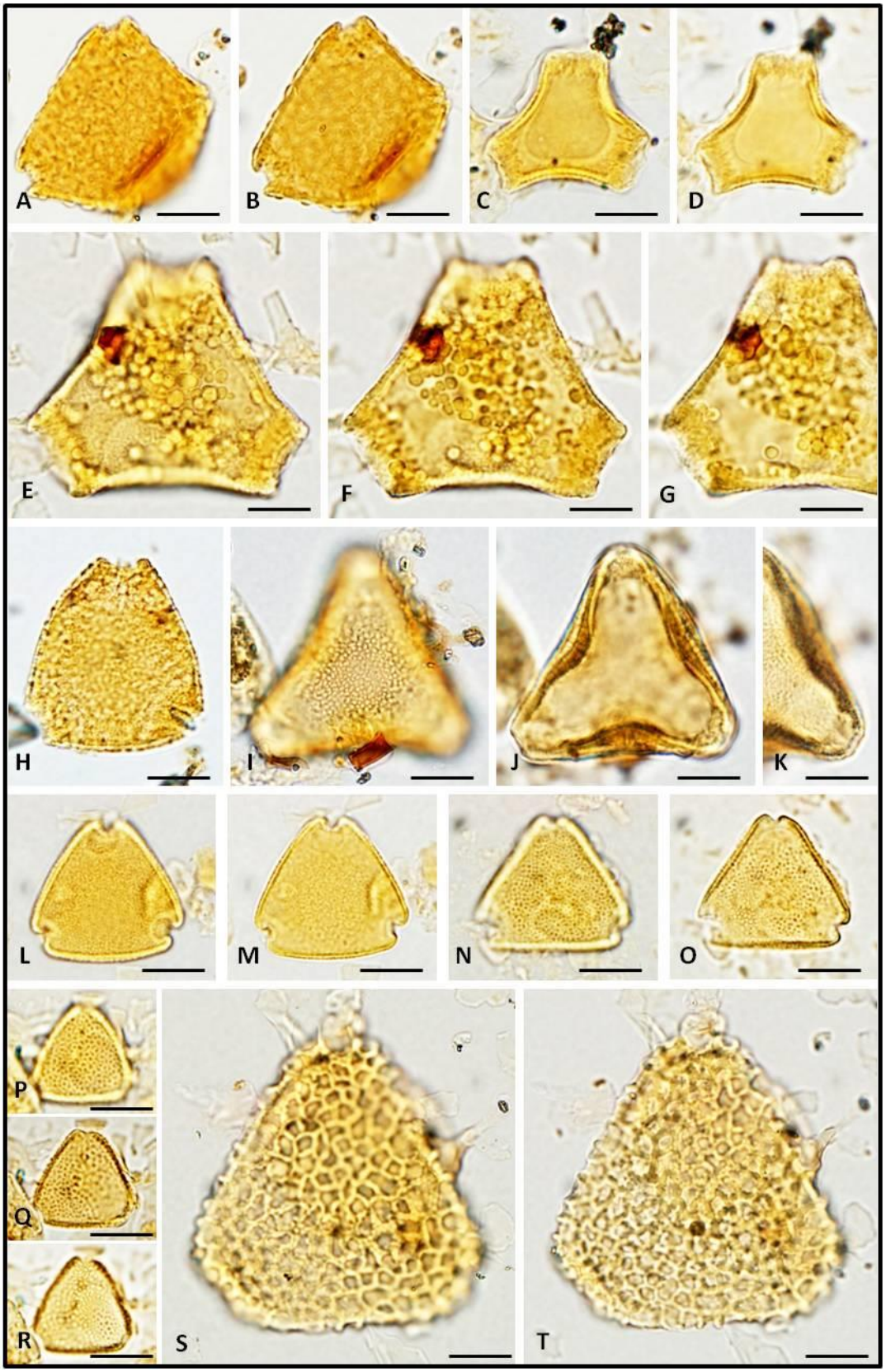

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T

PLATE 16

Photomicrographs of triporate angiosperm pollen. All scale bars 10µm.

Figures

A–E	*Proteacidites crassus*, A–C same grain, D, E same grain
F, G	*Proteacidites cumulus*, same grain
H, I	*Proteacidites* cf. *grandis*, same grain
J, K	*Proteacidites* aff. *Grevillea*, same grain
L	*Proteacidites* aff. *Isopogon*
M	*Proteacidites ivanhoensis*

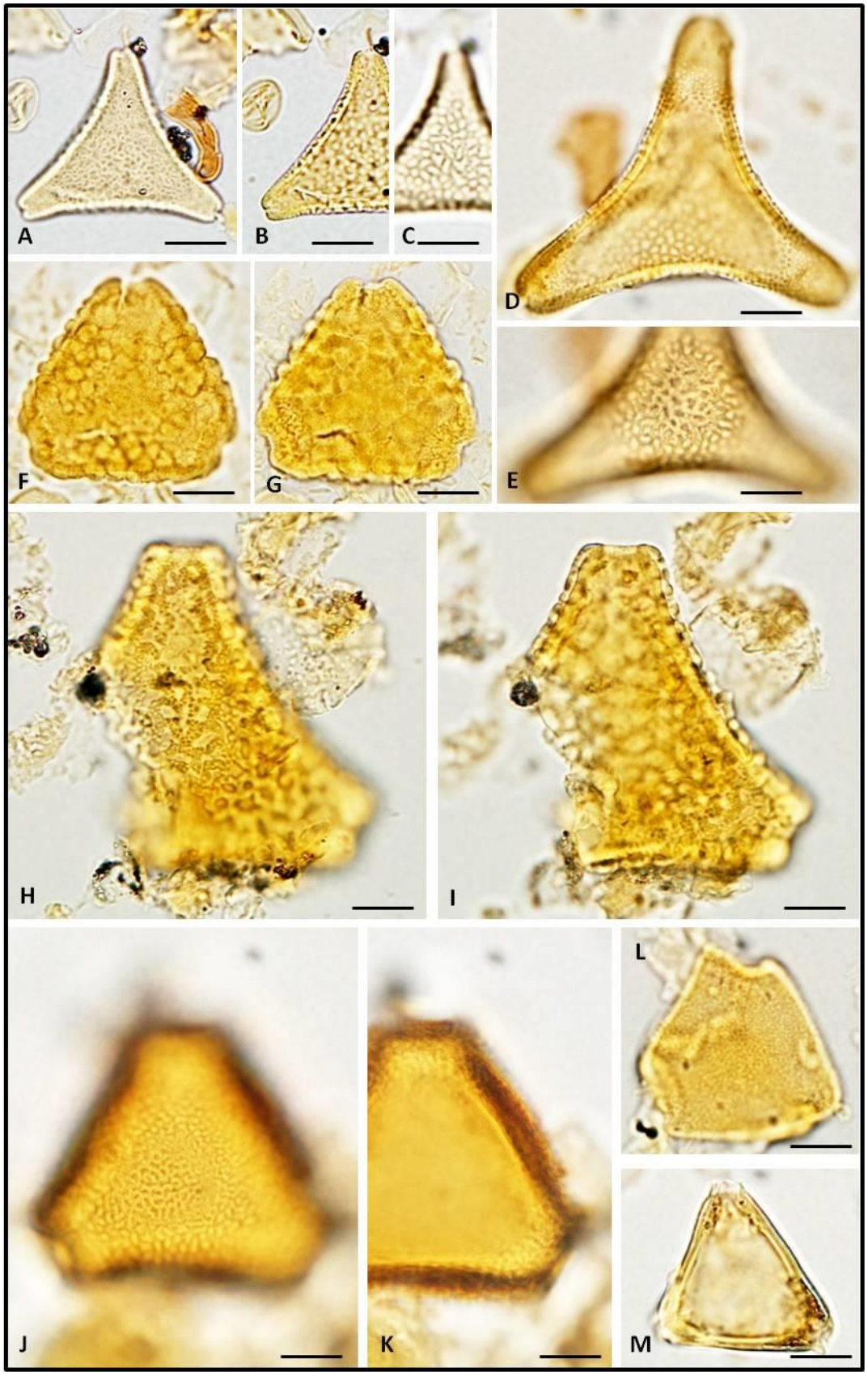

A
B
C
D
F
G
E
H
I
J
K
L
M

PLATE 17

Photomicrographs of triporate angiosperm pollen. All scale bars 10µm.

Figures

A, B	*Proteacidites kopiensis*, same grain
C, D	*Proteacidites* cf. *leightonii*, same grain
E	*Proteacidites leightonii* sculpture
F, G	*Proteacidites* cf. *microverrucatus*, same grain
H–J	*Proteacidites nasus*, same grain
K–N	*Proteacidites nasus* (small), same grain

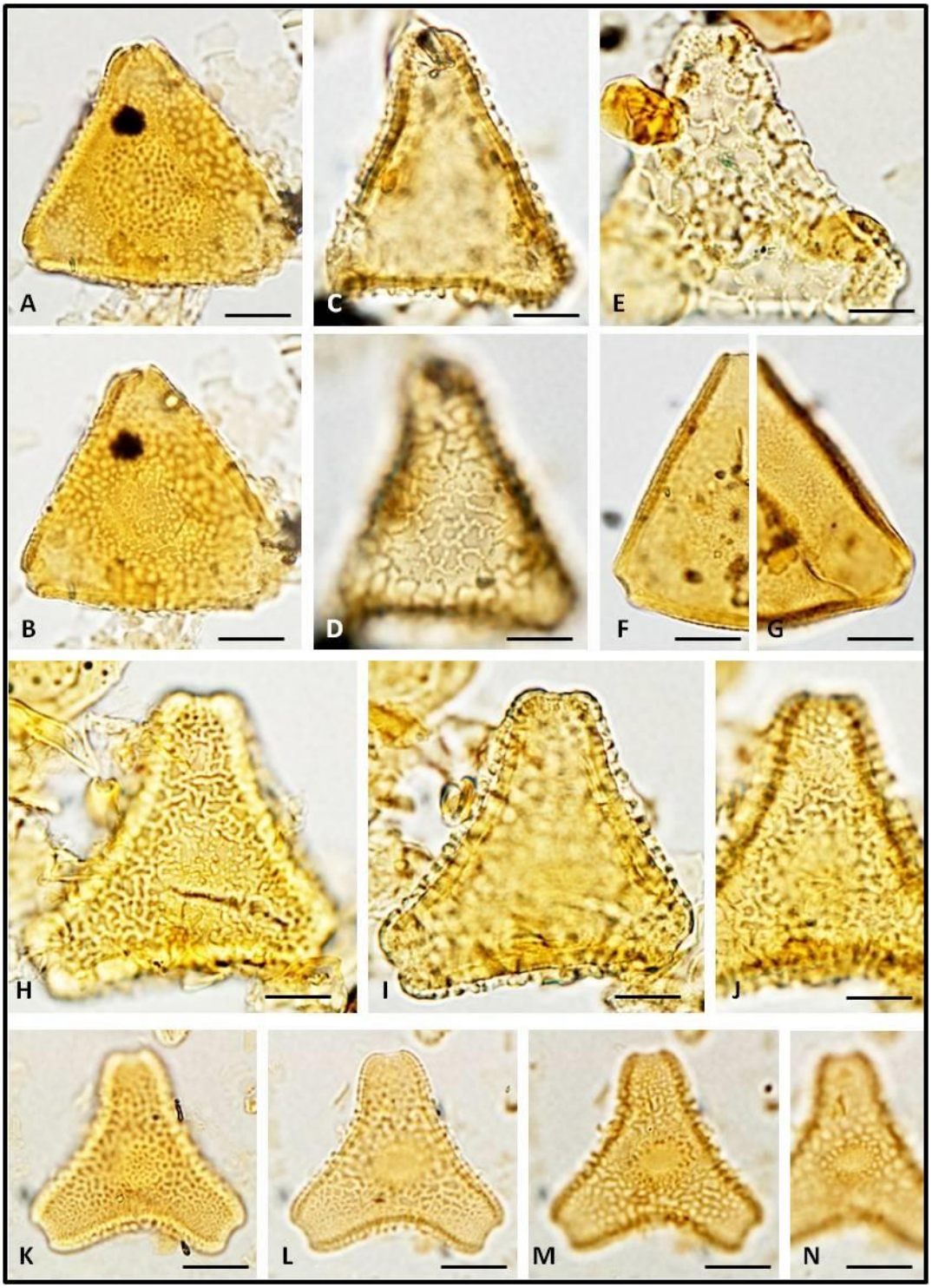

A
C
E
B
D
F
G
H
I
J
K
L
M
N

PLATE 18

Photomicrographs of triporate angiosperm pollen. All scale bars 10µm.

Figures

A–C *Proteacidites* cf. *nexinus*, same grain

D, E *Proteacidites* cf. *nitidus*, same grain

F, G *Proteacidites* '*notredamus'*, same grain

H–M *Proteacidites obscurus,* H, I same grain (stripped sexine), J, K same grain (rugulate sexine), L, M same grain (baculate sexine)

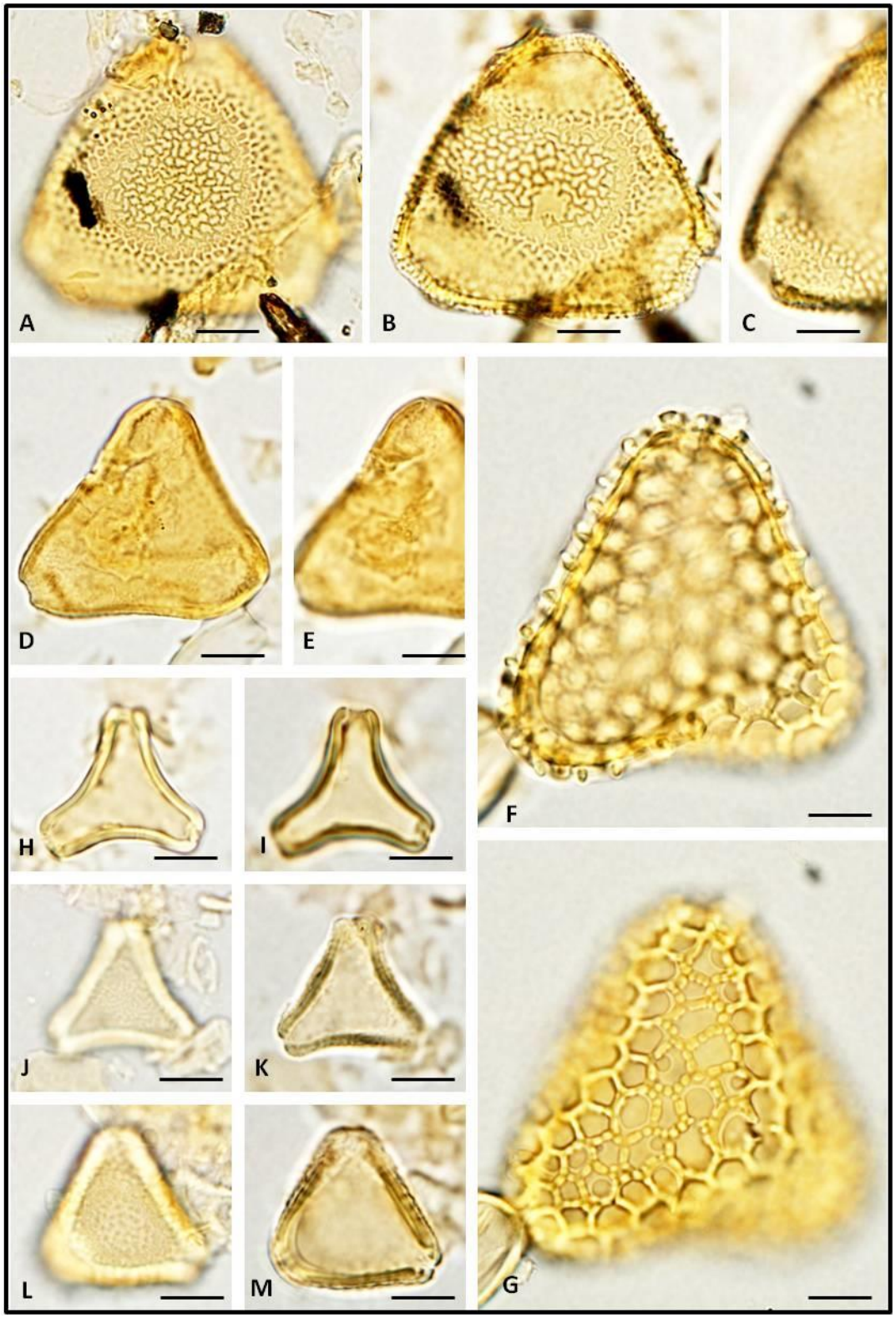

A
B
C
D
E
F
H
I
J
K
L
M
G

PLATE 19

Photomicrographs of triporate angiosperm pollen. All scale bars 10µm.

Figures

A–C	*Proteacidites* cf. *ornatus*, same grain
D–F	*Proteacidites pachypolus*, same grain
G, H	*Proteacidites pseudomoides*, same grain
I, J	*Proteacidites* cf. *pseudomoides* sp. 1, same grain
K	*Proteacidites* cf. *pseudomoides* sp. 3, same grain
L, M	*Proteacidites punctiporus*, same grain
N, O	*Proteacidites rectomarginis*, same grain
P, Q	*Proteacidites rectus*¸ same grain
R, S	*Proteacidites reticulatus*, same grain

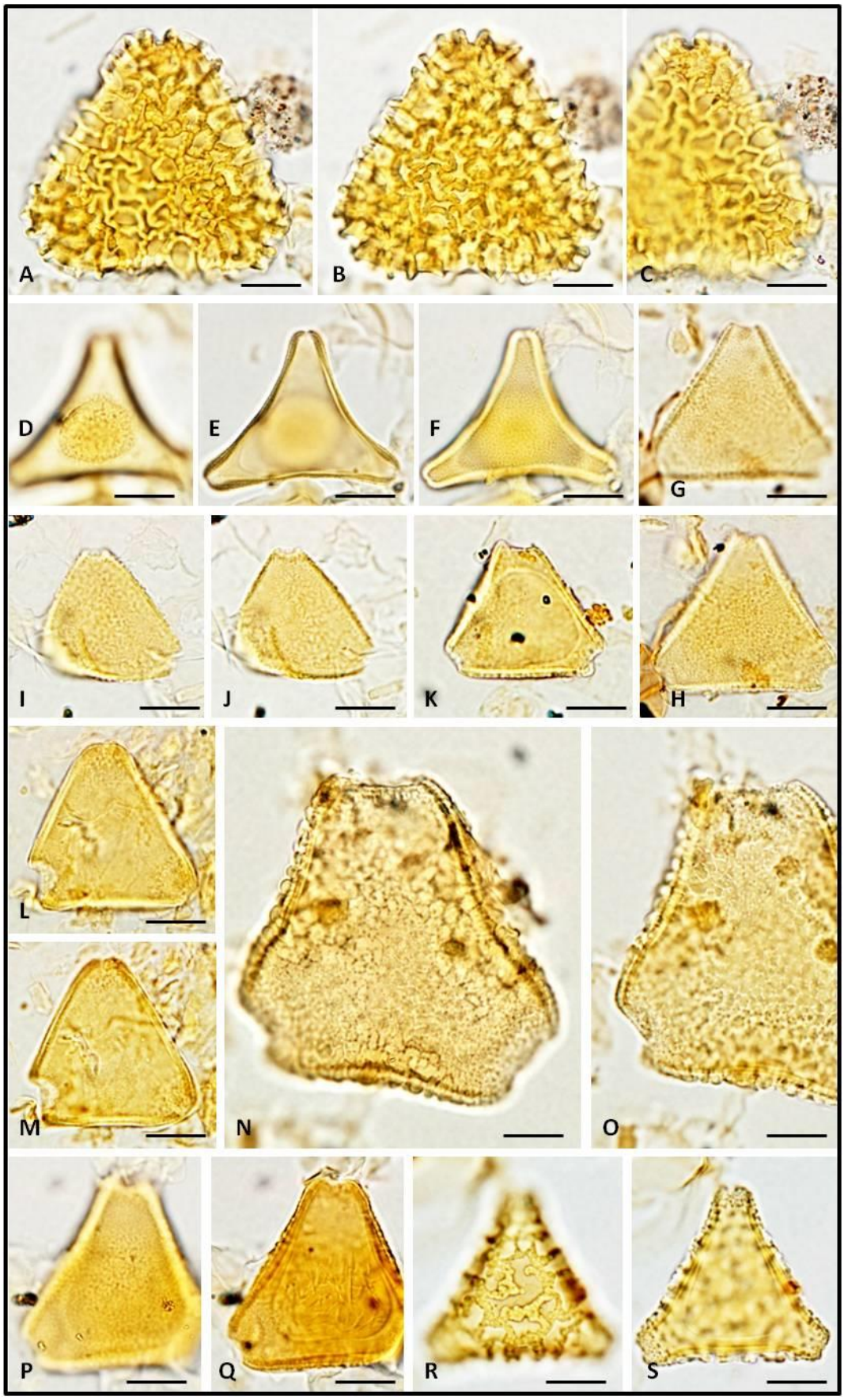

A
B
C
D
E
F
G
I
J
K
H
L
M
N
O
P
Q
R
S

PLATE 20

Photomicrographs of triporate angiosperm pollen. All scale bars 10µm.

Figures

A–D	*Proteacidites* cf. *reticulatus*, A, B same grain, C, D same grain
E–J	*Proteacidites rynthius*, E, F same grain, G, H same grain, I, J same grain
K, L	*Proteacidites scitus*, same grain
M, N	*Proteacidites simplex*, same grain
O–Q	*Proteacidites* cf. *stipplatus*, same grain
R	*Proteacidites subscabratus*

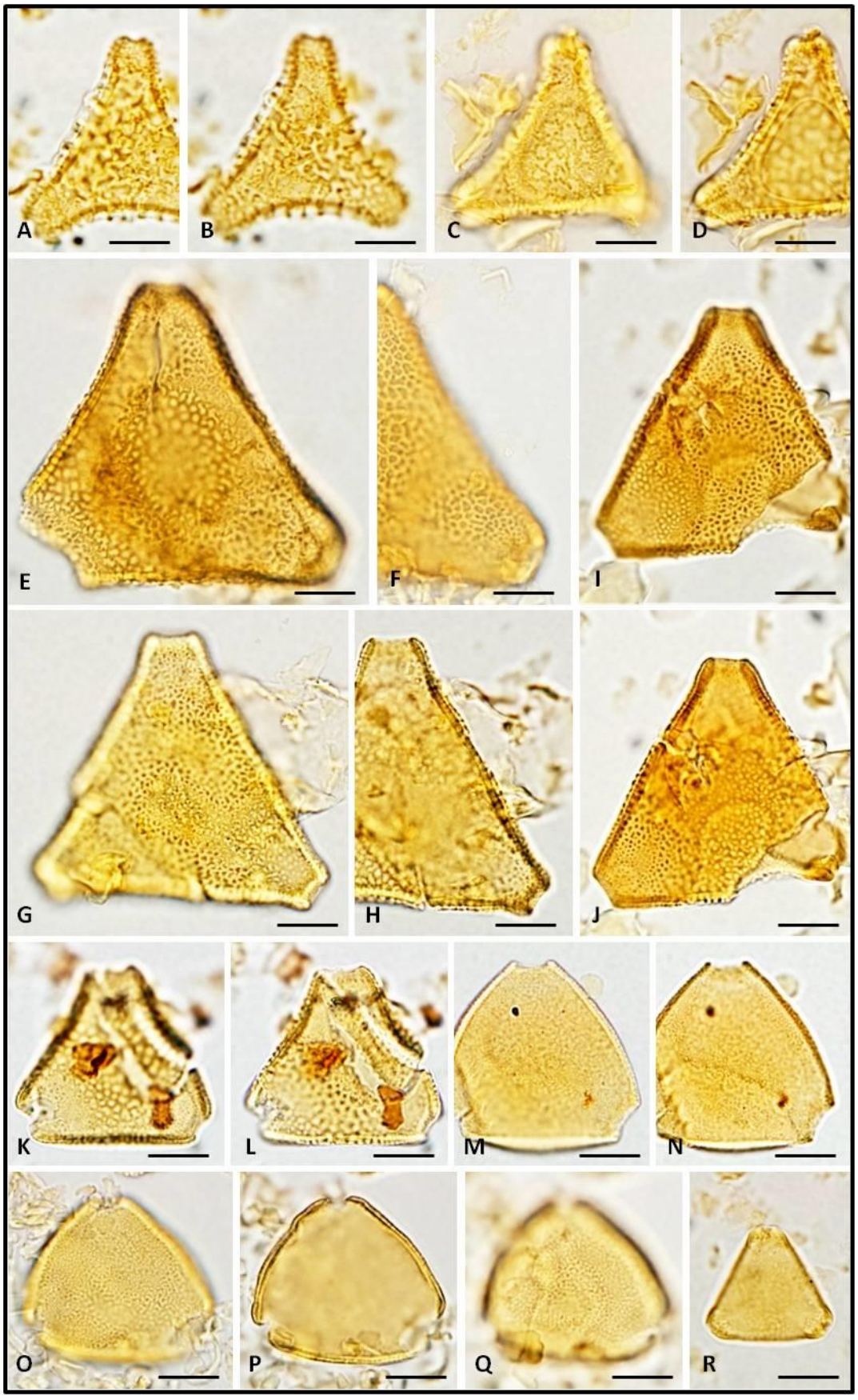

A
B
C
D
E
F
I
G
H
J
K
L
M
N
O
P
Q
R

PLATE 21

Photomicrographs of triporate angiosperm pollen. All scale bars 10μm.

Figures

A, B	*Proteacidites symphyonemoides*, same grain
C, E	*Proteacidites tenuiexinus*, same grain
F–H	*Proteacidites tuberculatus*, same grain
I, J	*Proteacidites tuberculiformis*, same grain
K, L	*Triporopollenites ambiguus*, same grain
M, N	*Triporopollenites delicatus*, same grain
O–Q	*Triporopollenites vargus*, same grain

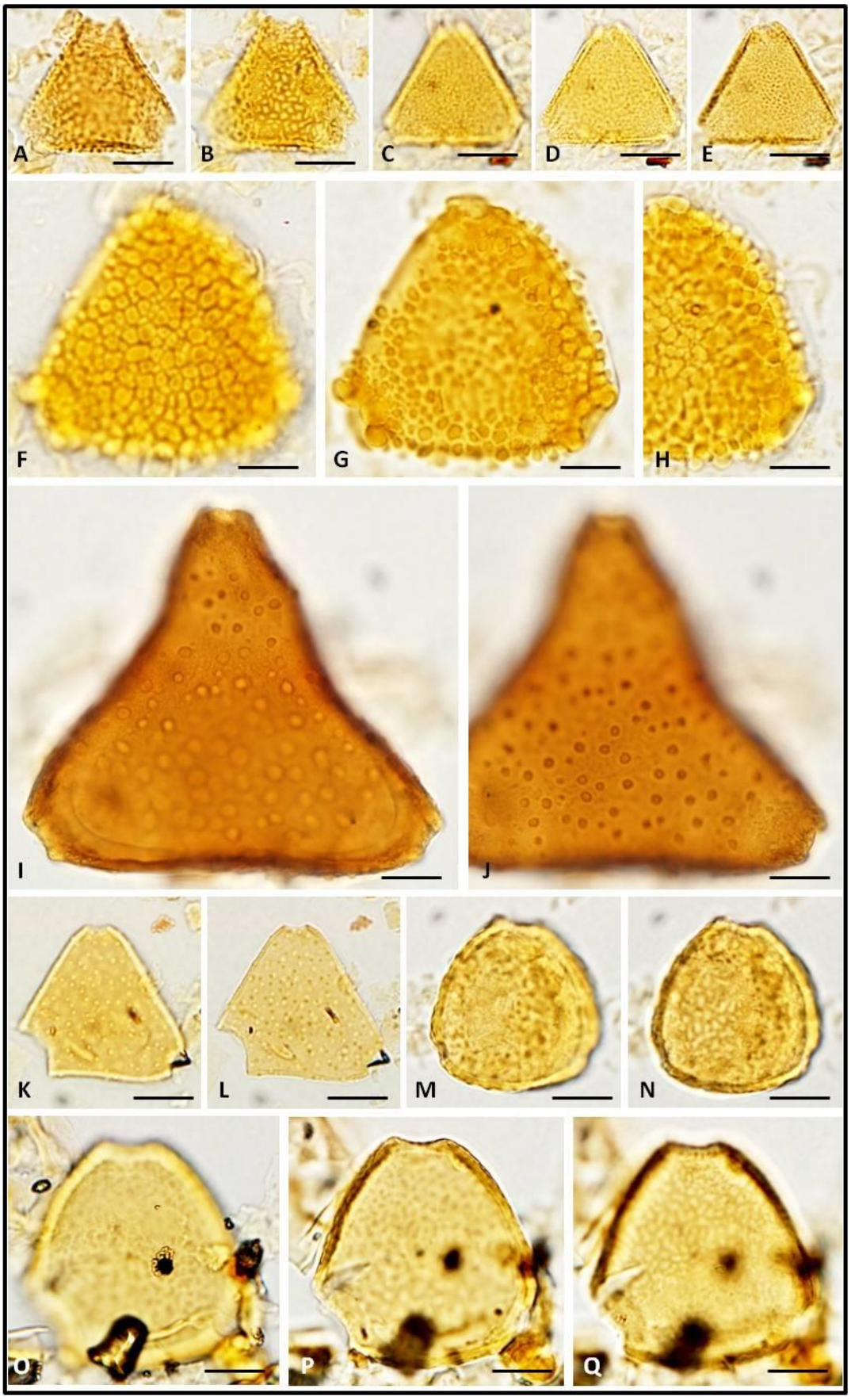
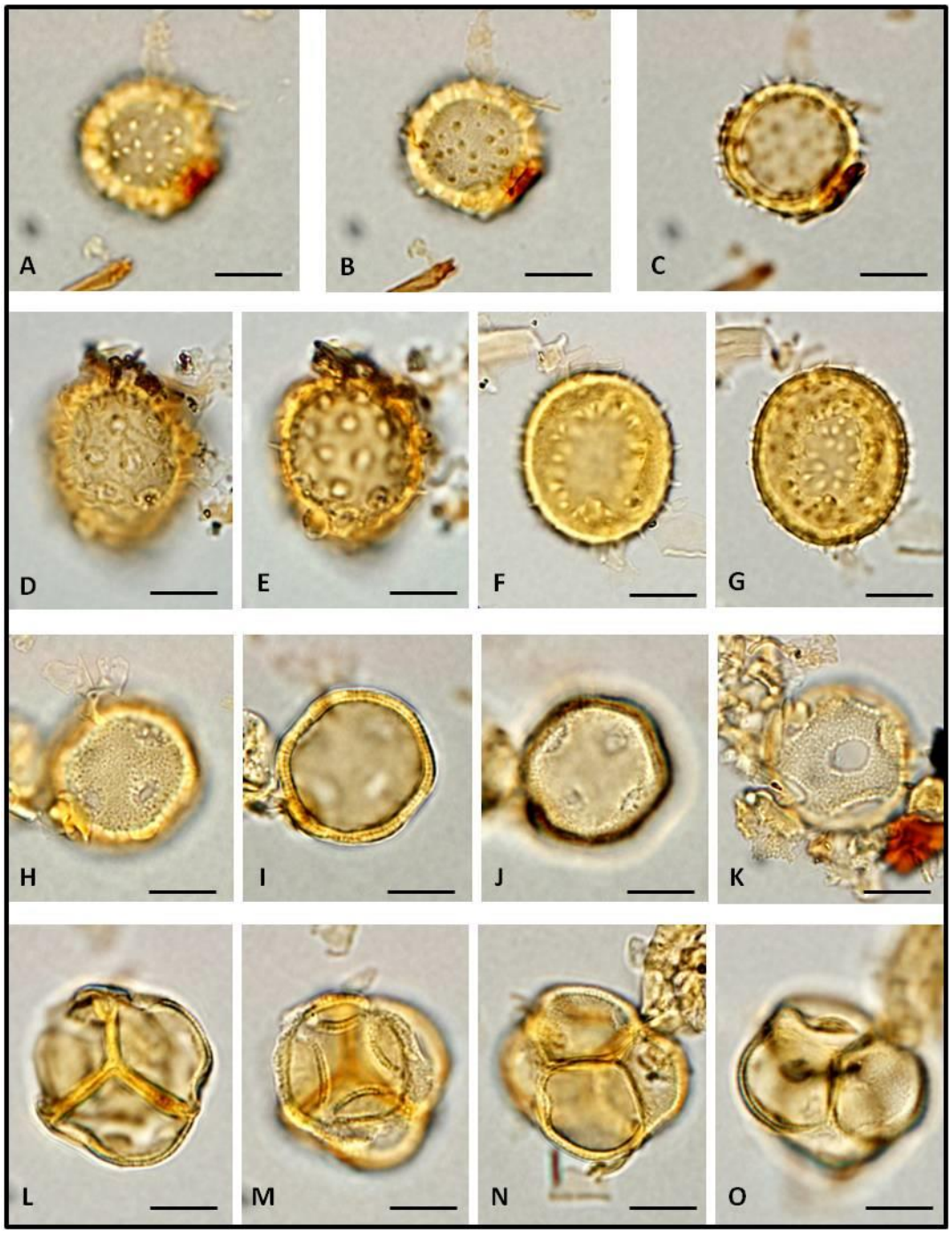

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q

PLATE 22

Photomicrographs of stephanoporate and periporate angiosperm pollen and pollen retained in tetrad. All scale bars 10μm.

Figures

A–C	*Malvacipollis diversus*, same grain
D, E	*Malvacipollis spinyspora*, same grain
F, G	*Malvacipollis subtilis*, same grain
H–K	*Periporopollenites demarcatus,* H–J same grain
L–O	*Ericipites scabratus,* L, M same grain, N, O same grain


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O

APPENDIX 6B: Photomicrographs of new species

PLATE 23

New species of spore and tricolpate pollen. Scale bars 10 µm. **A–C.** *Cyathidites* sp., same grain. **A.** Low focus on lasurae. **B.** Median focus on thickening of wall interradially. **C.** High focus on rugulate surface. **D.** *Rugulatisporites* sp., median focus. **E.** Spore sp. A., median focus. **F.** Spore sp. B., median focus. **G, H.** *Tricolpites discoides* holotype. **G.** Median focus on exine stratification. **H.** Low focus on scabrate sculpture. **I.** *Tricolpites discoides,* median focus on smaller specimen showing same exine stratification. **J–L.** *Tricolpites occultum* holotype. **J.** High focus on colpi and reticulate sculpture. **K.** Median focus on exine stratification and two of three colpi. **L.** Low magnification. **M.** *Tricolpites occultum,* med-high focus on grain showing orientation that conceals colpi in exine. **N, O.** *Tricolpites reticularis* holotype. **N.** Med-high focus on exine stratification and reticulate sculpture. **O.** Med-low focus. **P.** *Tricolpites reticularis,* high focus on specimen with thinner exine. **Q, R.** *Tricolpites reticuloides* paratype. **Q.** Low focus on reticulate sculpture. **R.** Med-high focus on wall stratification and sculpture.

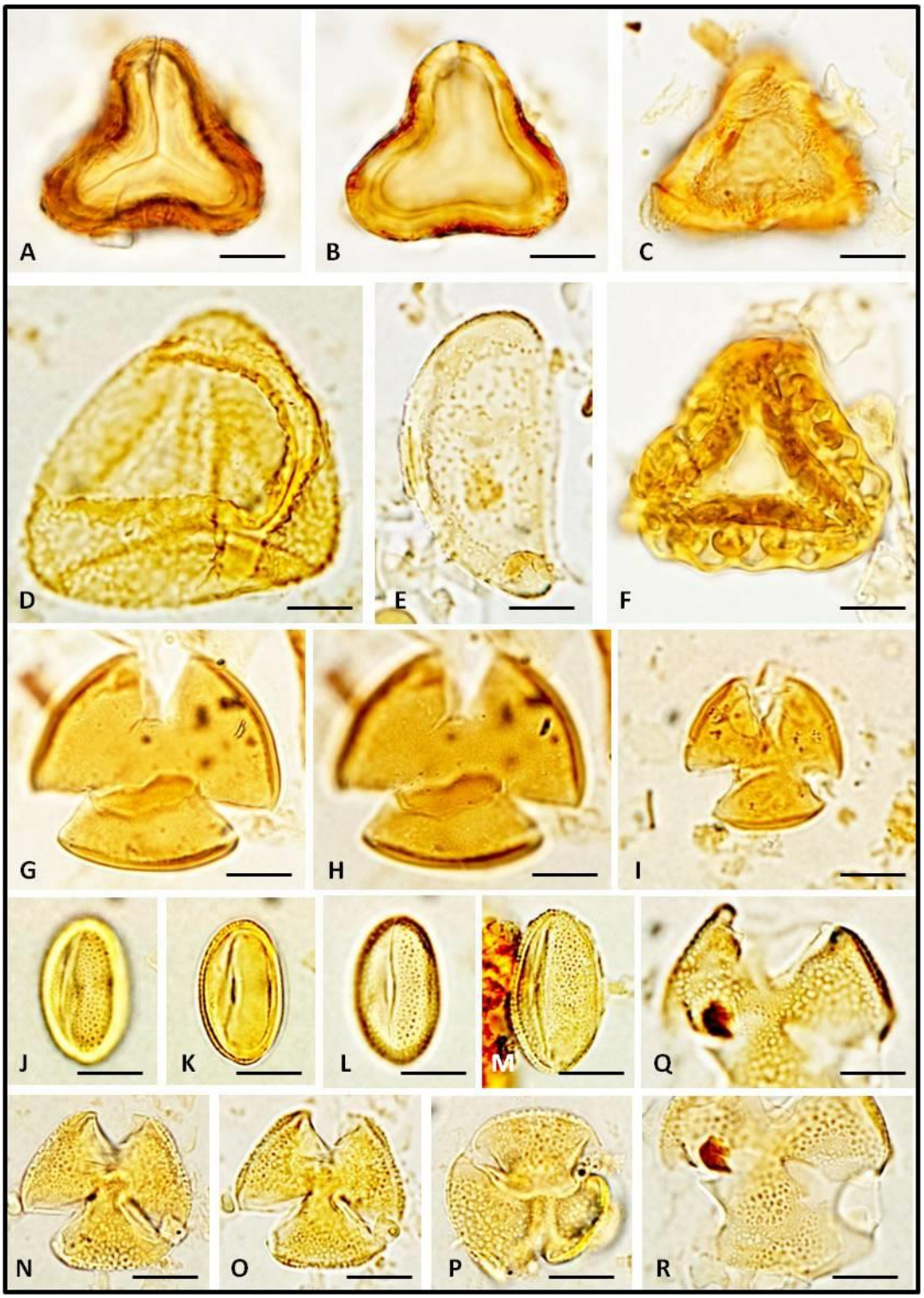

A
B
C
D
E
F
G
H
I
J
K
L
M
Q
N
O
P
R

PLATE 24

New species of tricolpate, tricolporate and syncolporate pollen. **A, B.** *Tricolpites* sp. A. **A.** Med-low focus showing exine stratification and finely reticulate sculpture. **B.** Median focus showing consistent exine thickness. **C, D.** *Tricolpites* sp. B, same grain. **C.** Med-low focus on finely echinate surface. **D.** Median focus showing exine stratification and cross section of spines of the sexine. **E–G.** *Rhoipites oralongii* same grain. **E.** Median focus showing lalongate pores and exine stratification. **F.** Low focus on colpi, showing lack of external pore. **G.** High focus on reticulate sculpture. **H–K.** *Rhoipites orbiculatus* holotype. **H.** High focus on reticulate sculpture and colpi. **I.** Median focus one exine stratification. **J.** Med-high focus on colpi. **K.** Low focus on colpi and circular ora. **L–N.** *Rhoipites orbiculatus* paratype. **L.** High focus on circular ora and colpi. **M.** Med-low focus showing exine stratification. **N.** Low focus on reticulate sculpture. **O–Q.** *Tricolporites* sp. B. **O, P.** High and median foci showing exine stratification and protrusion of nexine at the pore. **Q.** Low focus on microreticulate sculpture. **R–U.** *Rhoipites* sp. A. **R.** high focus on sculpture and circular ora. **S.** Med-high focus on exine stratification. **T.** Med- low focus. **U.** Low focus on surface sculpture and colpi. **V–X.** *Tricolporites* sp. A. **V.** High focus on perforate sculpture. **W.** Med-low focus on colpi. **X.** Median focus on colpi, and exine stratification. **Y, Z.** *Myrtaceidites corymbioides* holotype. **Y.** Med-low focus showing psilate sculpture and pores. **Z.** Median high focus on exine stratification.

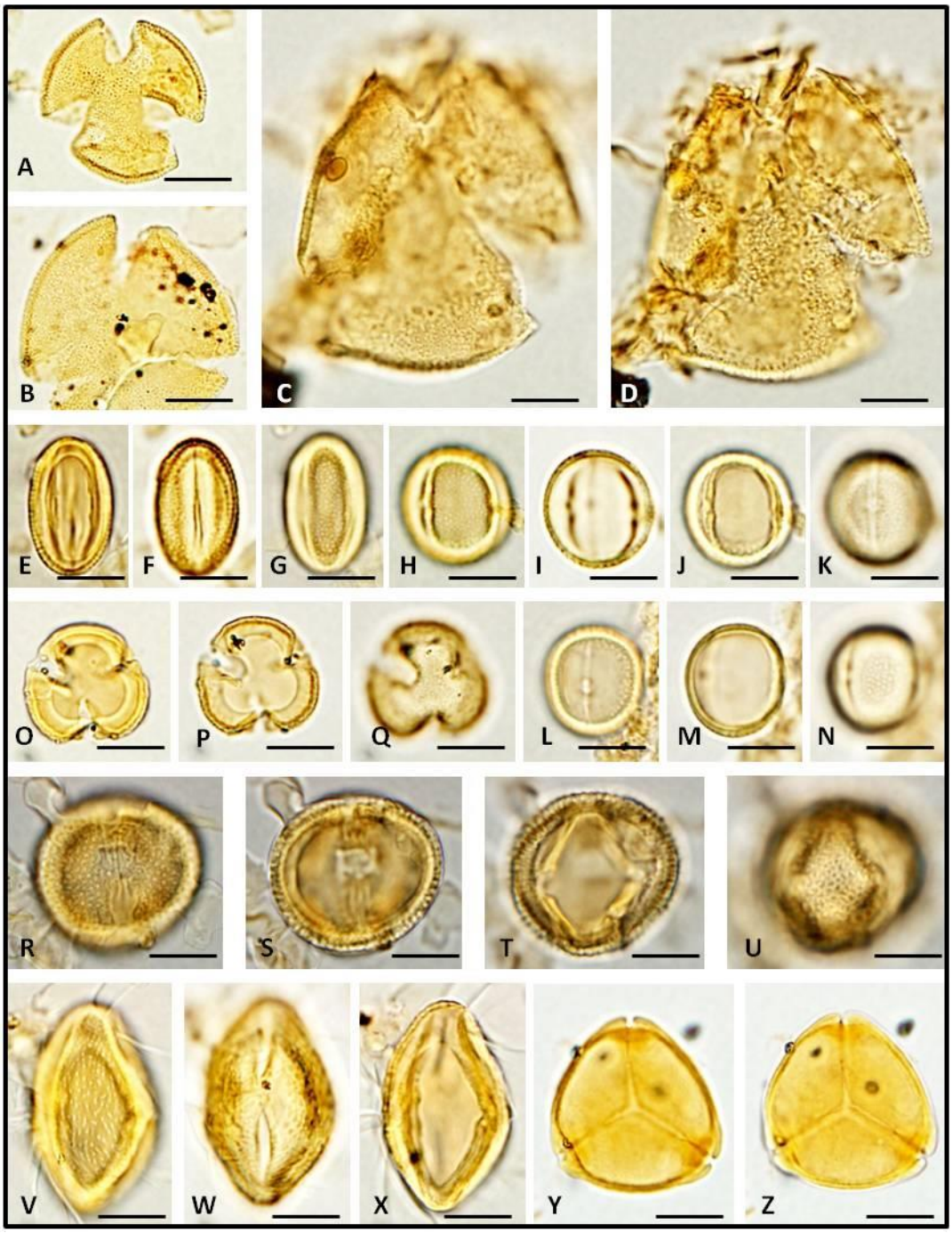

A
B
C
D
E
F
G
H
I
J
K
O
P
Q
L
M
N
R
S
T
U
V
W
X
Y
Z

PLATE 25

New *Proteacidites* species. **A–F.** *Proteacidites ambassadatus.* **A–C.** Holotype. **A.** Med-high focus showing per-reticulate to finely reticulate sculpture. **B.** Median focus on exine stratification and annulate thinning at aperture. **C.** Low focus on polar protuberance. **D–F.** Paratype. **D.** Med-high focus on per-reticulate to finely reticulate surface. **E.** Median focus showing exine stratification. **F.** Low focus showing polar protuberance. **G–L.** *Proteacidites colubrimodus*. **G–I.** Holotype. **G.** Med-high focus showing reticulate sexine on the convex side of the grain. **H.** Median focus showing exine stratification and pores. **I.** Low focus on concave side. **J–L.** Paratype. **J.** Med-high focus on concave side showing reticulate sexine and exine stratification at the aperture. **K.** Median focus on exine stratification mesoporially. **L.** Low focus on convex side.

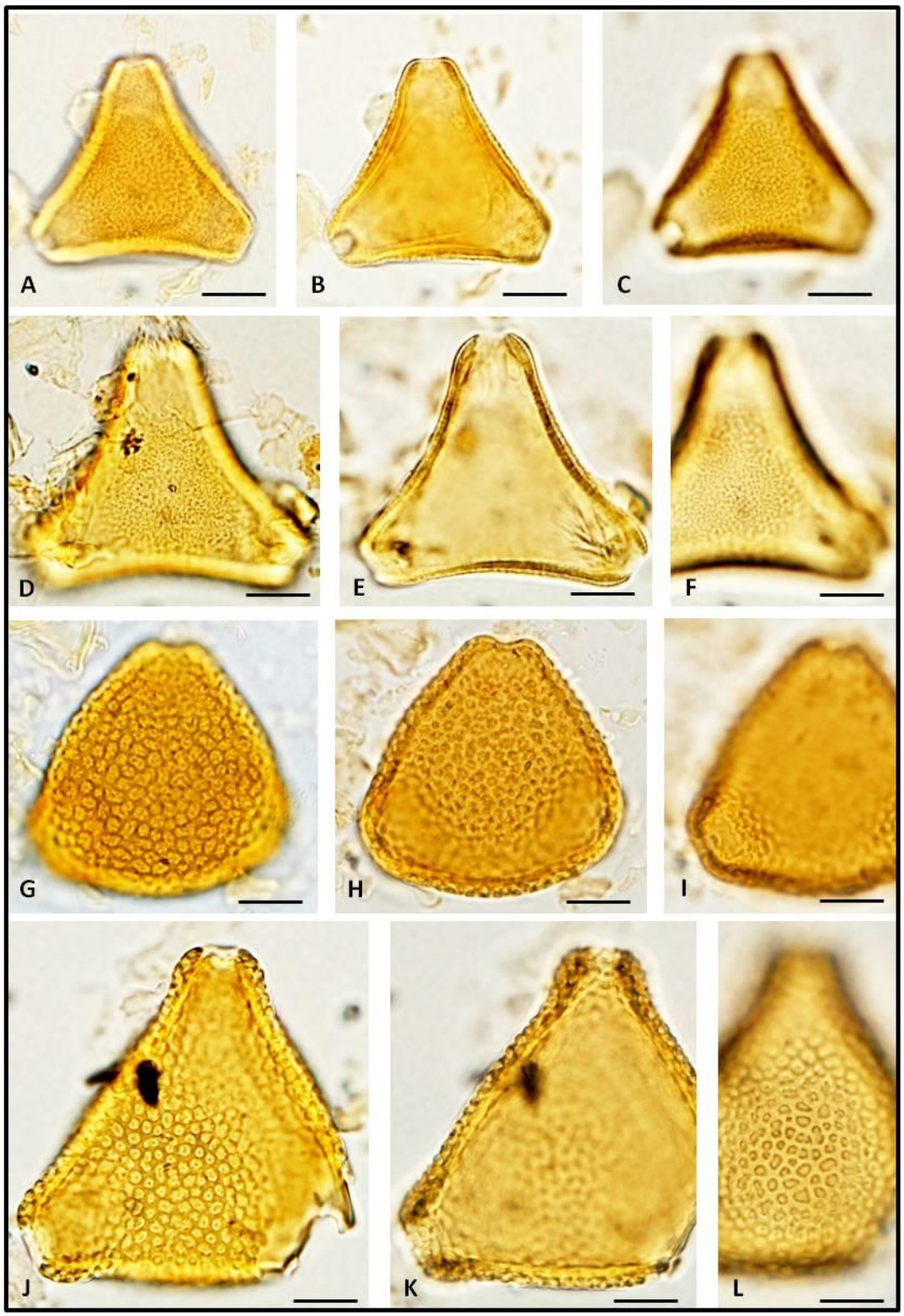

A
B
C
D
E
F
G
H
I
J
K
L

PLATE 26

New *Proteacidites* species. **A–C.** *Proteacidites colubrimodus*, same grain with additional pore. **A.** Med-high focus showing reticulum. **B.** Median to low focus. **C.** Median focus on exine stratification and aperture morphology. **D–G.** *Proteacidites crochetaria* , holotype. **D.** High focus on reticulum. **E.** Med-high focus on collumelae. **F.** Median focus on exine stratification. **G.** Med-low focus showing collumellae in the infratectum. **H–L.** *Proteacidites microspinosus.* **H –J.** Holotype. **H.** High focus on spines. **I.** Median focus on mesoporial exine stratification. **J.** Med-low focus on exine stratification at the aperture. **K, L.** Paratype. **K.** Median to low focus on exine stratification. **L.** Med-high focus on spine bases. **M–P.** *Proteacidites narnooensis.* **M, N.** Holotype. **M.** High focus on finely granulate sculpture. **N.** Median focus on exine stratification and annulate thinning prior to aperture. **O, P.** Paratype. **O.** High focus on granulate surface sculpture. **P.** Med-low focus showing mesoporial thickening. **Q–T.** *Proteacidites polygonalis.* **Q, R.** Holotype. **Q.** Med-high focus on reticulum and exine stratification. **R.** Low focus on reticulum. **S, T.** Paratype. **S.** Med-high focus on reticulum and sexine. **T.** Med-low focus showing exine stratification and reticulum.

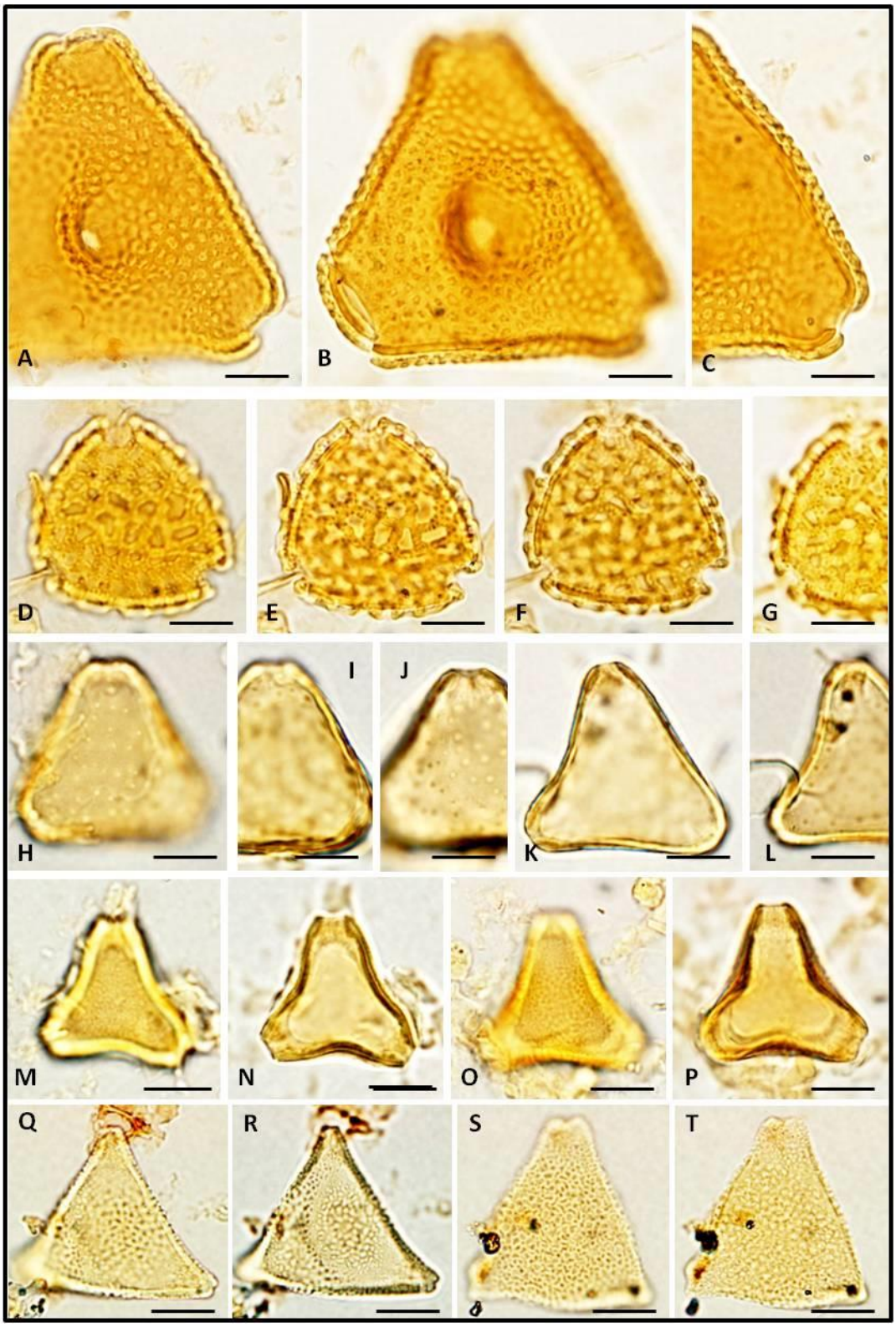

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T

PLATE 27

New *Proteacidites* species. **A–F.** *Proteacidites protrudens.* **A–C.** Holotype. **A.** Low focus on reticulum. **B.** Median focus on exine stratification. **C.** Med-high focus on reticulum and striate exine at apertures. **D–F.** Paratype. **D.** High focus on reticulum. **E.** Median focus on exine stratification and striate exine at aperture. **F.** Low focus on reticulum. **G–J.** *Proteacidites rickmanii,* holotype. **G.** High focus on reticulum. **H, I.** Med-high and med-low foci, showing exine stratification. **J.** Low focus on reticulum and apertural exine stratification.

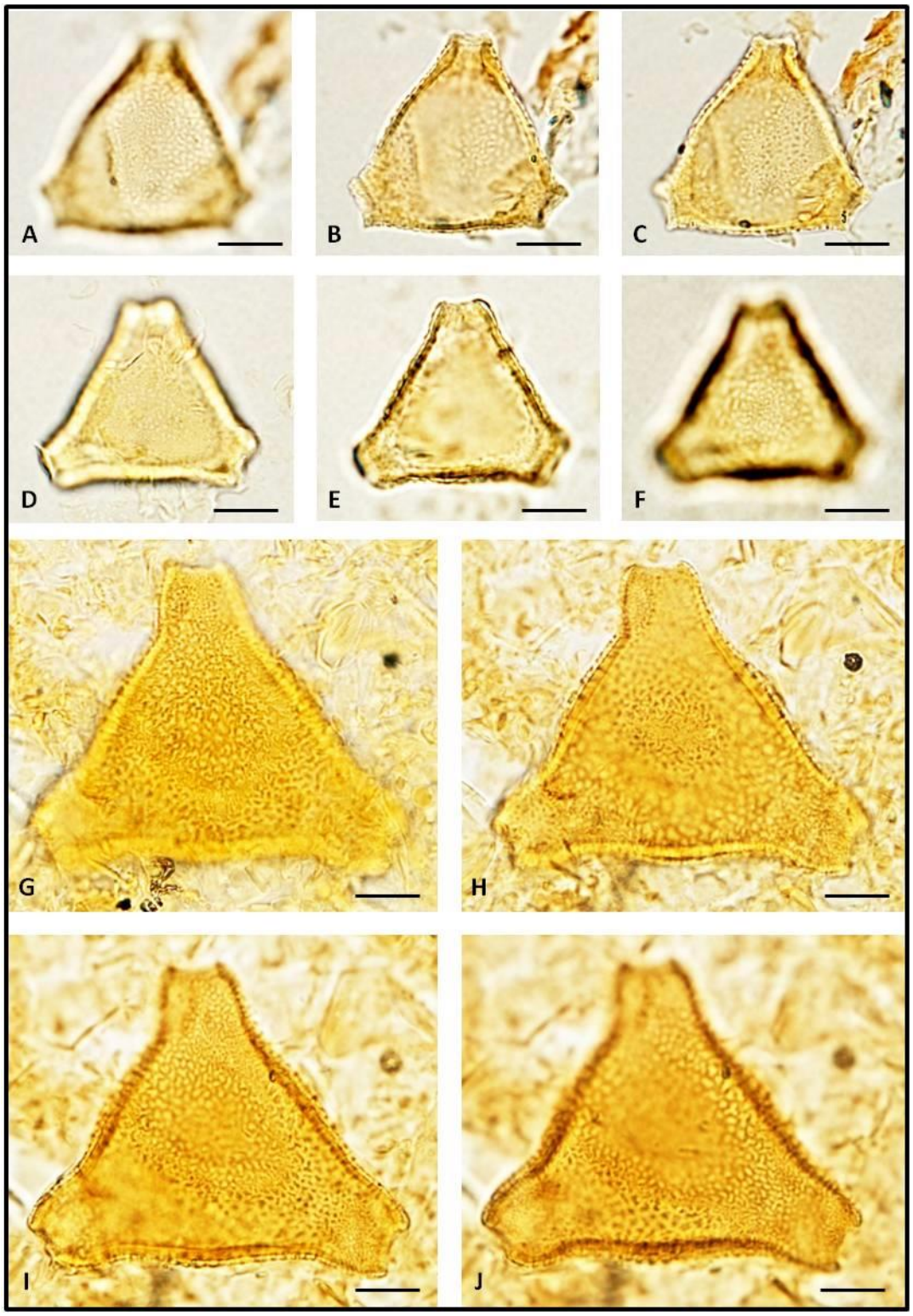

A
B
C
D
E
F
G
H
I
J

PLATE 28

New *Proteacidites* species. **A–E.** *Proteacidites tesselaria*. **A–C.** Holotype. **A.** High focus on reticulum. **B.** Low focus on reticulum. **C.** Median focus on exine stratification. **D, E.** Paratype. **D.** High focus on reticulum. **E.** Low focus. **F–K.** *Proteacidites vaga.* **F–I.** Holotype. **F.** High focus on granulae. **G.** Med-high focus on sculpture. **H.** Med-low focus on exine stratification. **I.** Low focus. **J, K.** Paratype. **J.** Med-high focus on exine, showing stratification at aperture and mesoporially. **K.** High focus on sculpture. **L, M.** *Proteacidites* sp. A. **L.** High focus on reticulum. **M.** Med-low focus on reticulum and exine. **N, O.** *Proteacidites* sp. B. **N.** High focus on perforate sculpture. **O.** Med-low focus showing exine. **P, Q.** *Proteacidites* sp. C. **P.** High focus on scabrate exine. **Q.** Med-low focus. **R, S.** *Proteacidites* sp. D. **R.** High focus on reticulum. **S.** Median focus on exine stratification. **T–W.** *Proteacidites* sp. E. **T.** High focus on reticulum. **U.** Med-high focus showing collumellae. **V.** Median focus on exine stratification. **W.** Low focus on reticulum.

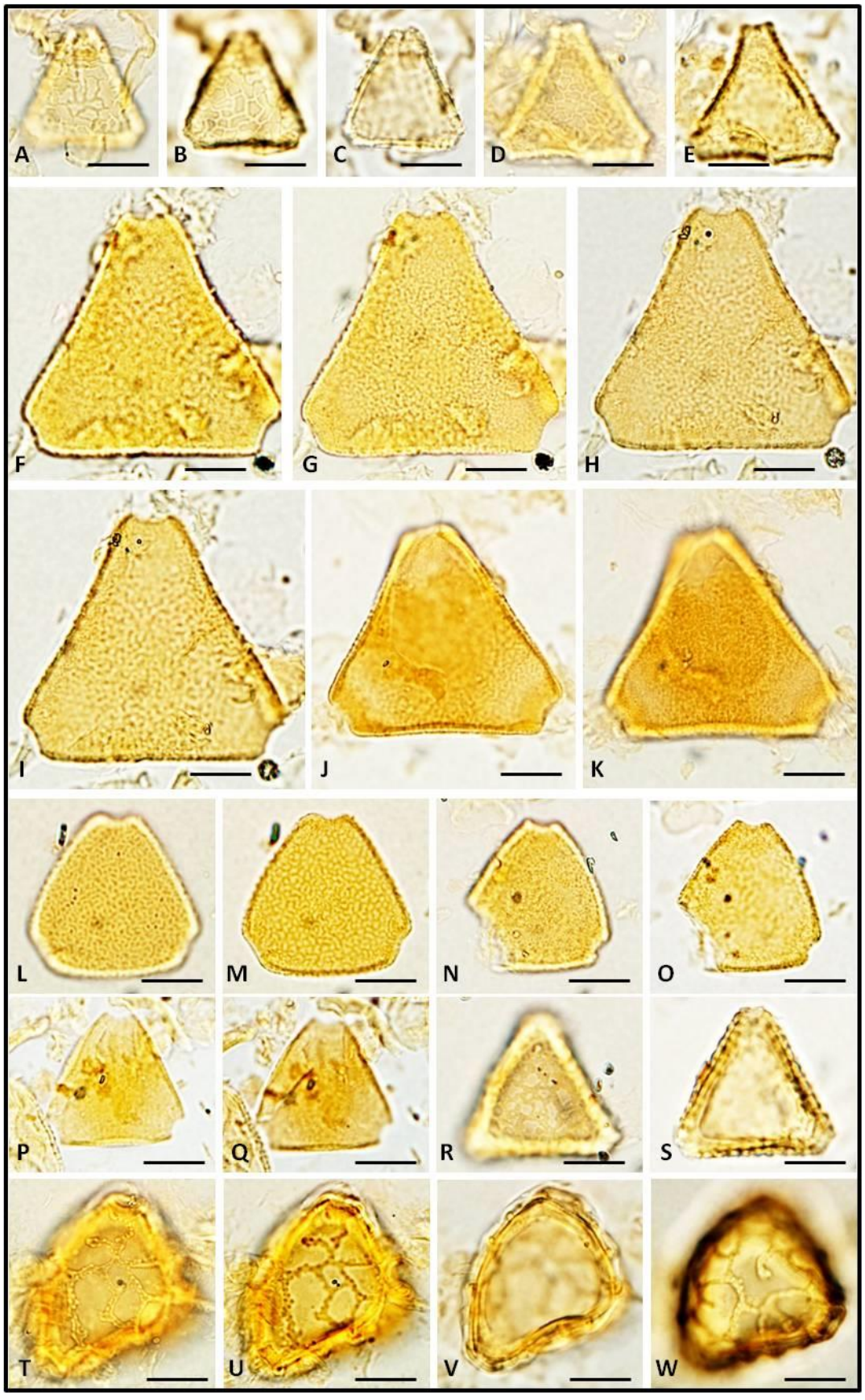
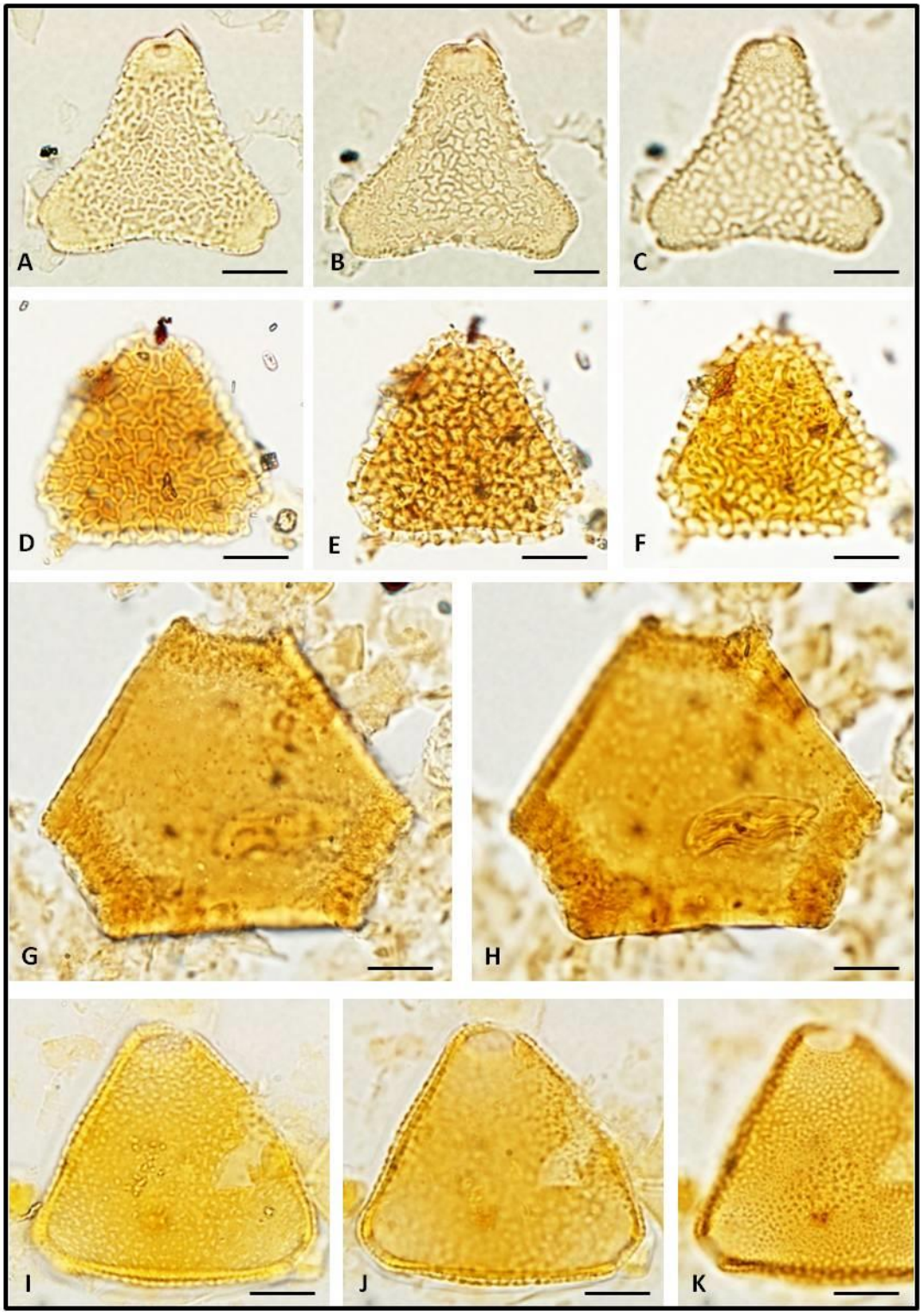

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W

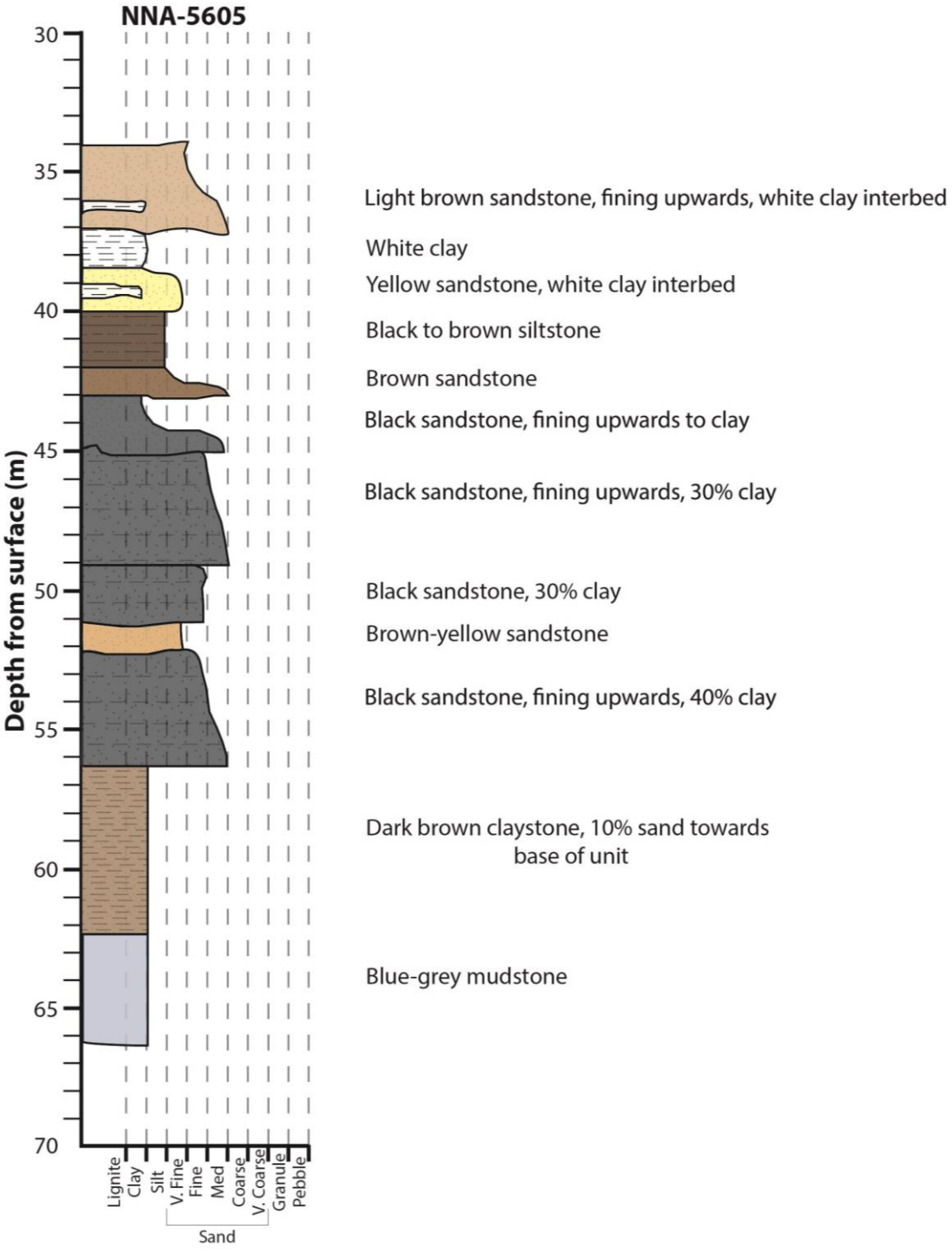
PLATE 29

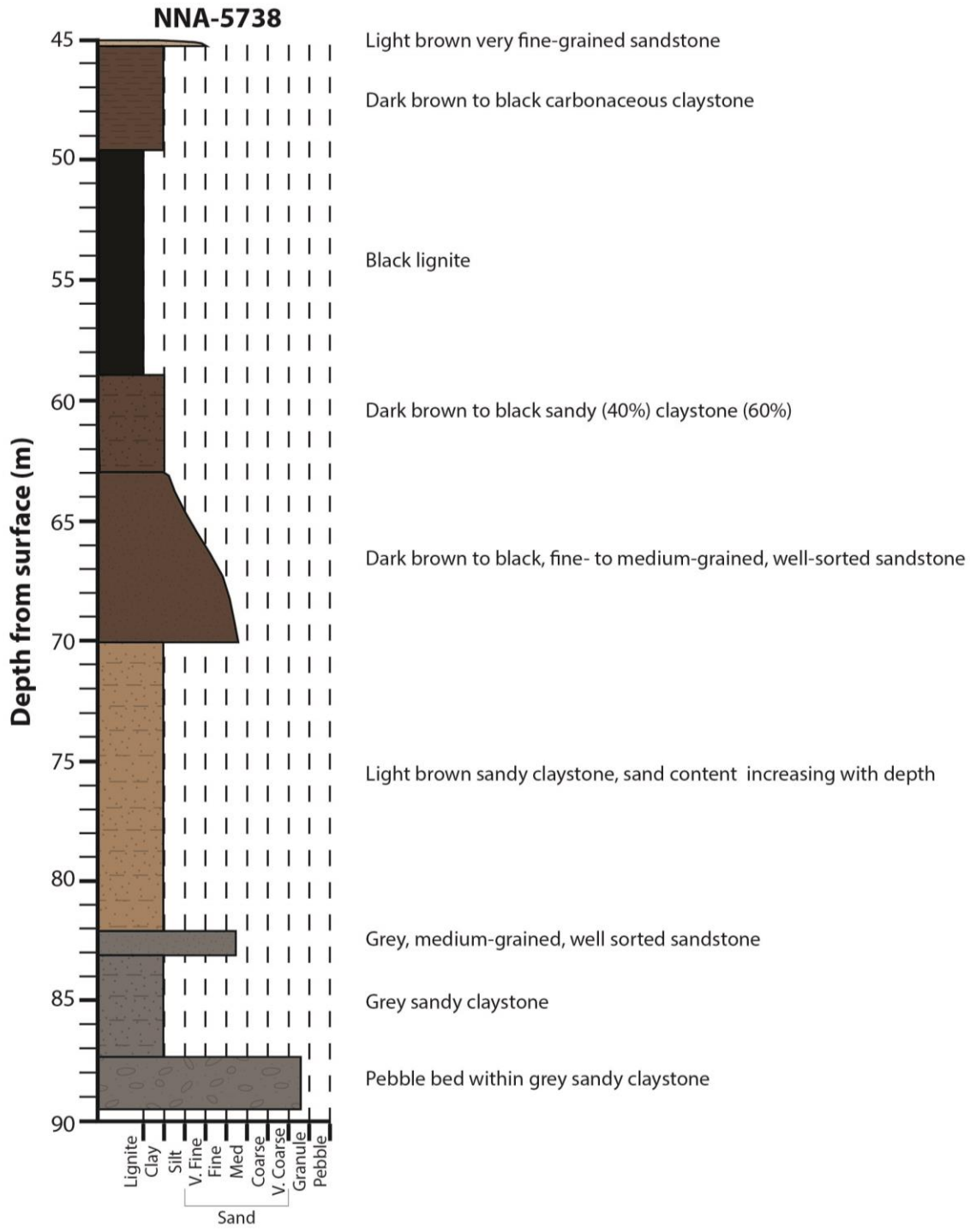
New *Proteacidites* species. **A–C.** *Proteacidites* sp. F. **A.** High focus on reticulum. **B.** Med-low focus on exine stratification. **C.** Low focus on perforate sculpture at the apertures. **D–F.** *Proteacidites* sp. G. **D.** High focus on reticulum. **E.** Median focus on exine stratification. **F.** Med-low focus on collumelae. **G, H.** *Proteacidites* sp. H. **G.** Median focus on exine stratification. **H.** Med-low focus on apertural collar. **I–K.** *Proteacidites* sp. I. **I.** Median focus on exine stratification. **J.** Median-low focus on aperture and exine stratification. **K.** Low focus on reticulum.

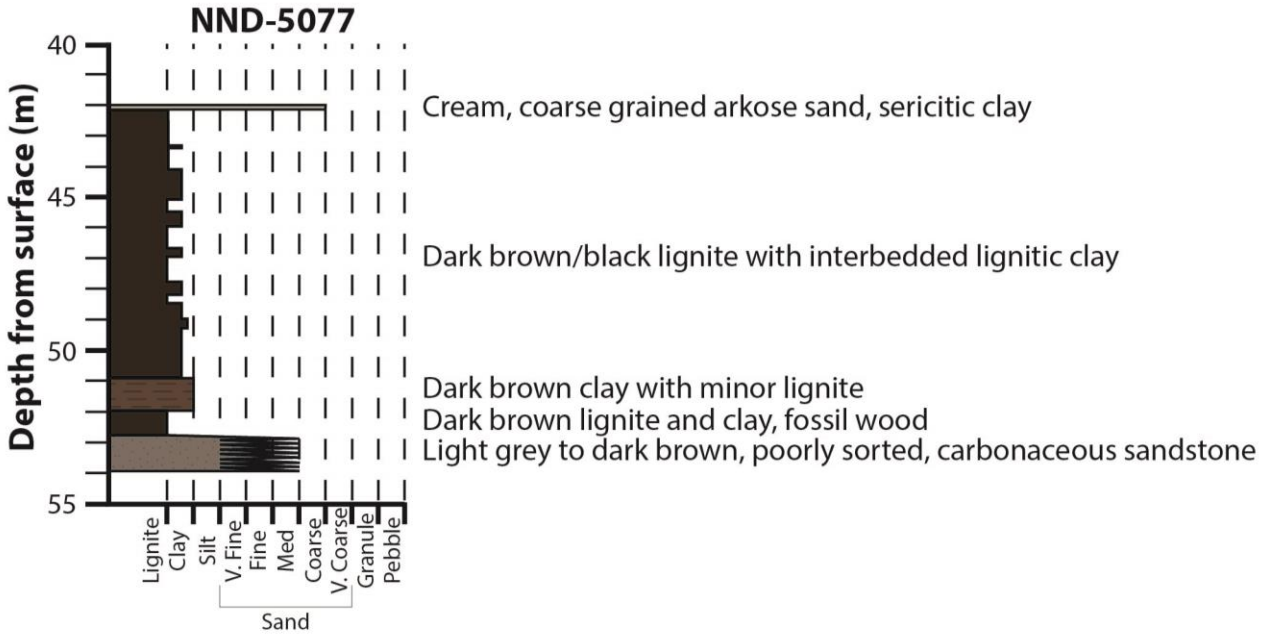

A
B
C
D
E
F
G
H
I
J
K

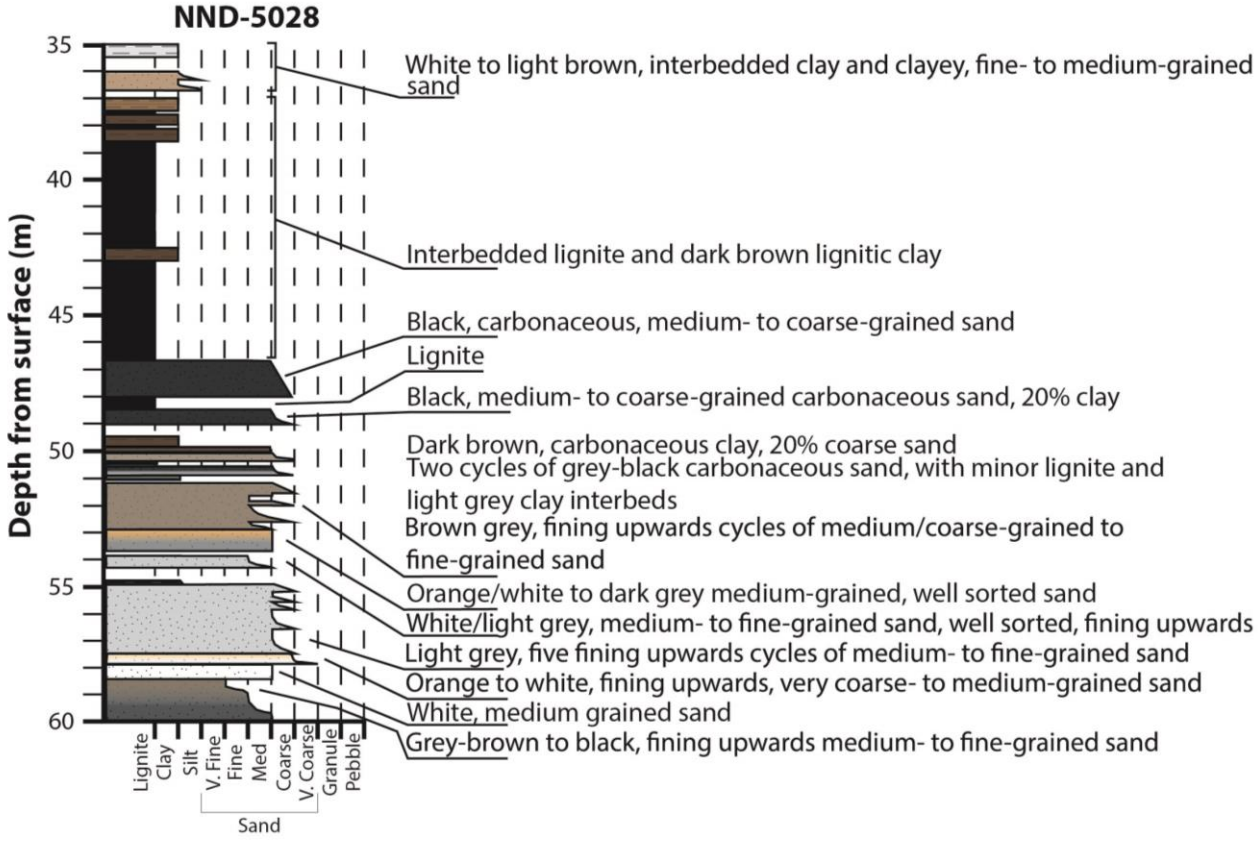
APPENDIX 7. Digitised drill hole logs.

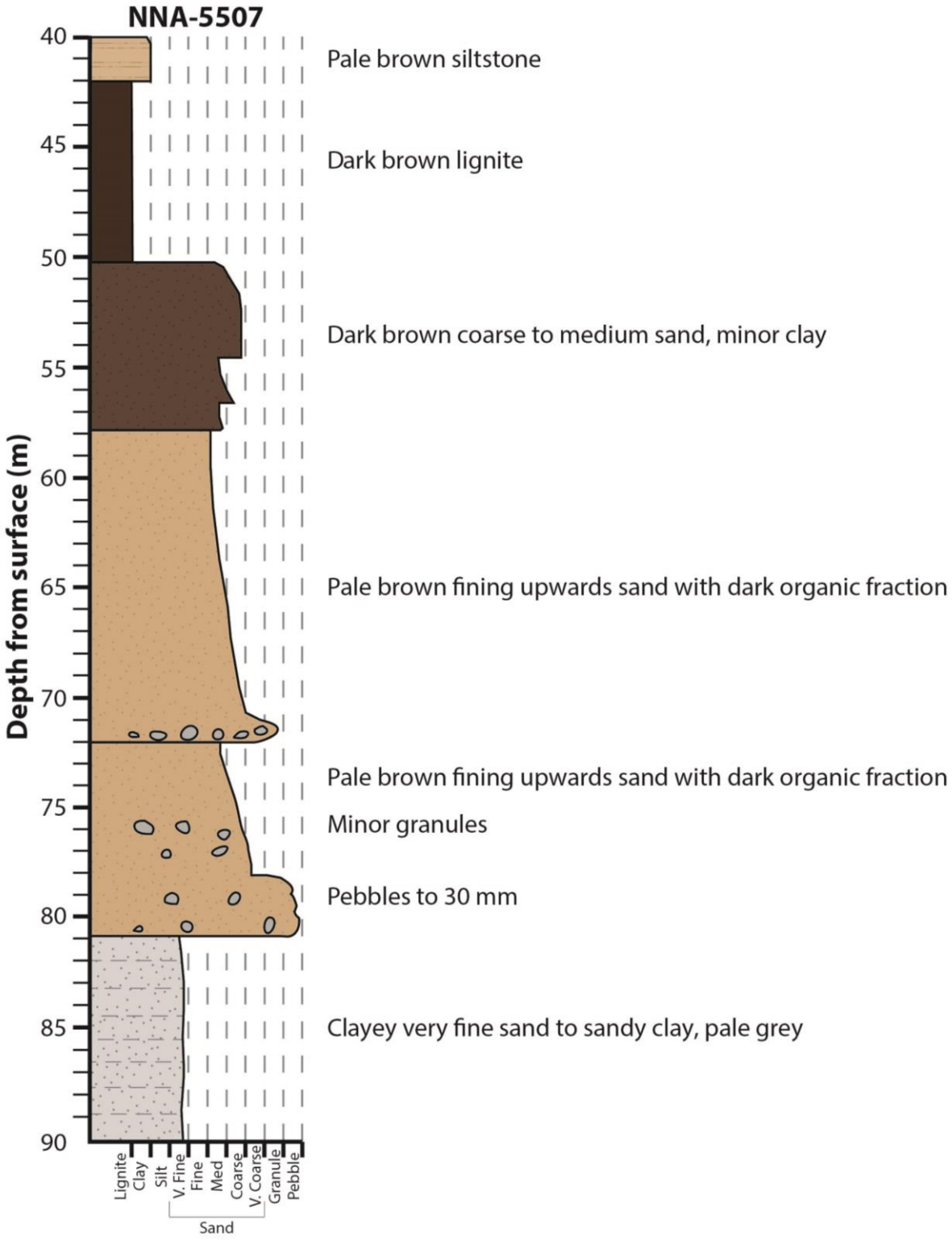
Compiled from hand drawn field logs provided by Vimy Resources Limited. Text as written by company geologists.

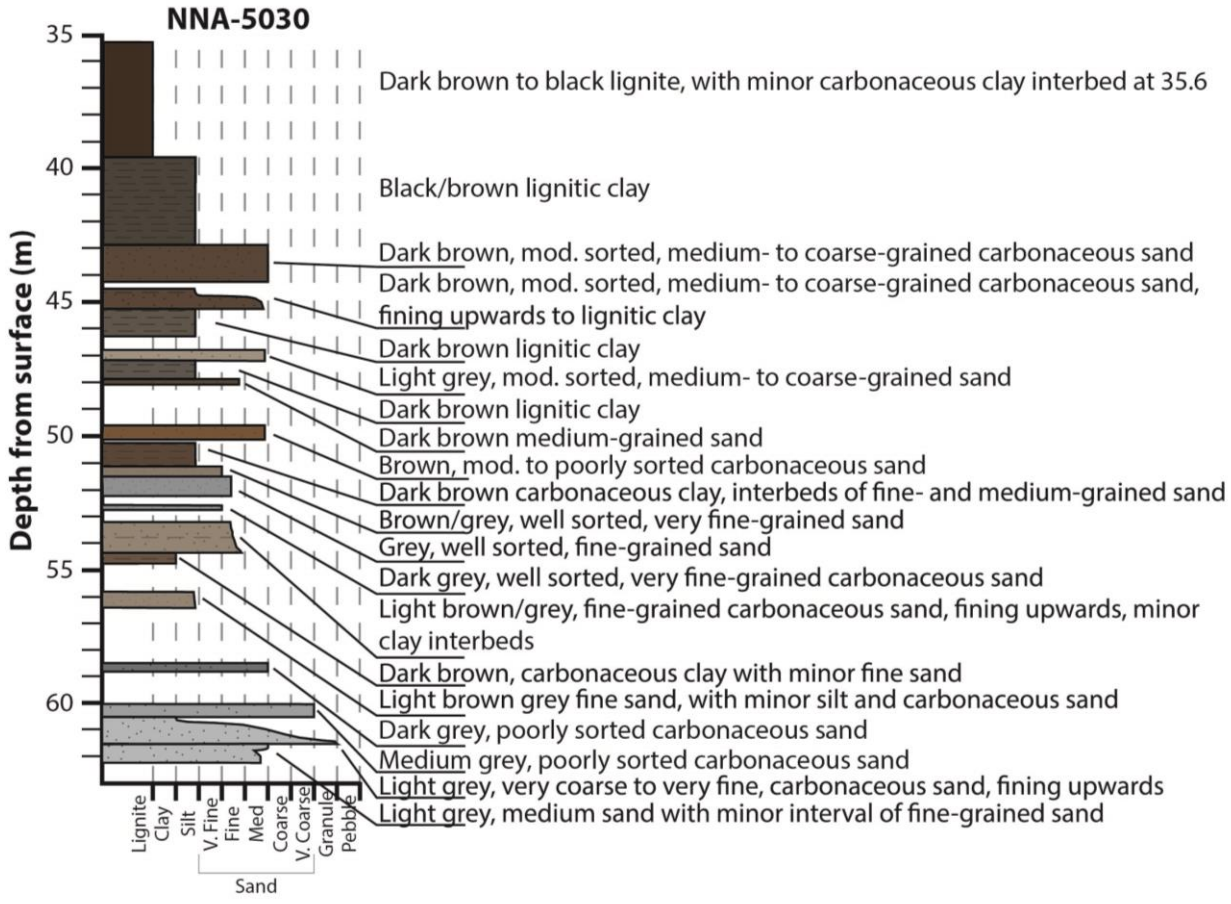

NNA-5605
Depth from surface (m)
30
35
40
45
50
55
60
65
70
Lignite
Clay
Silt
V. Fine
Fine
Med
Coarse
V. Coarse
Granule
Pebble
Sand
Light brown sandstone, fining upwards, white clay interbed
White clay
Yellow sandstone, white clay interbed
Black to brown siltstone
Brown sandstone
Black sandstone, fining upwards to clay
Black sandstone, fining upwards, 30% clay
Black sandstone, 30% clay
Brown-yellow sandstone
Black sandstone, fining upwards, 40% clay
Dark brown claystone, 10% sand towards base of unit
Blue-grey mudstone

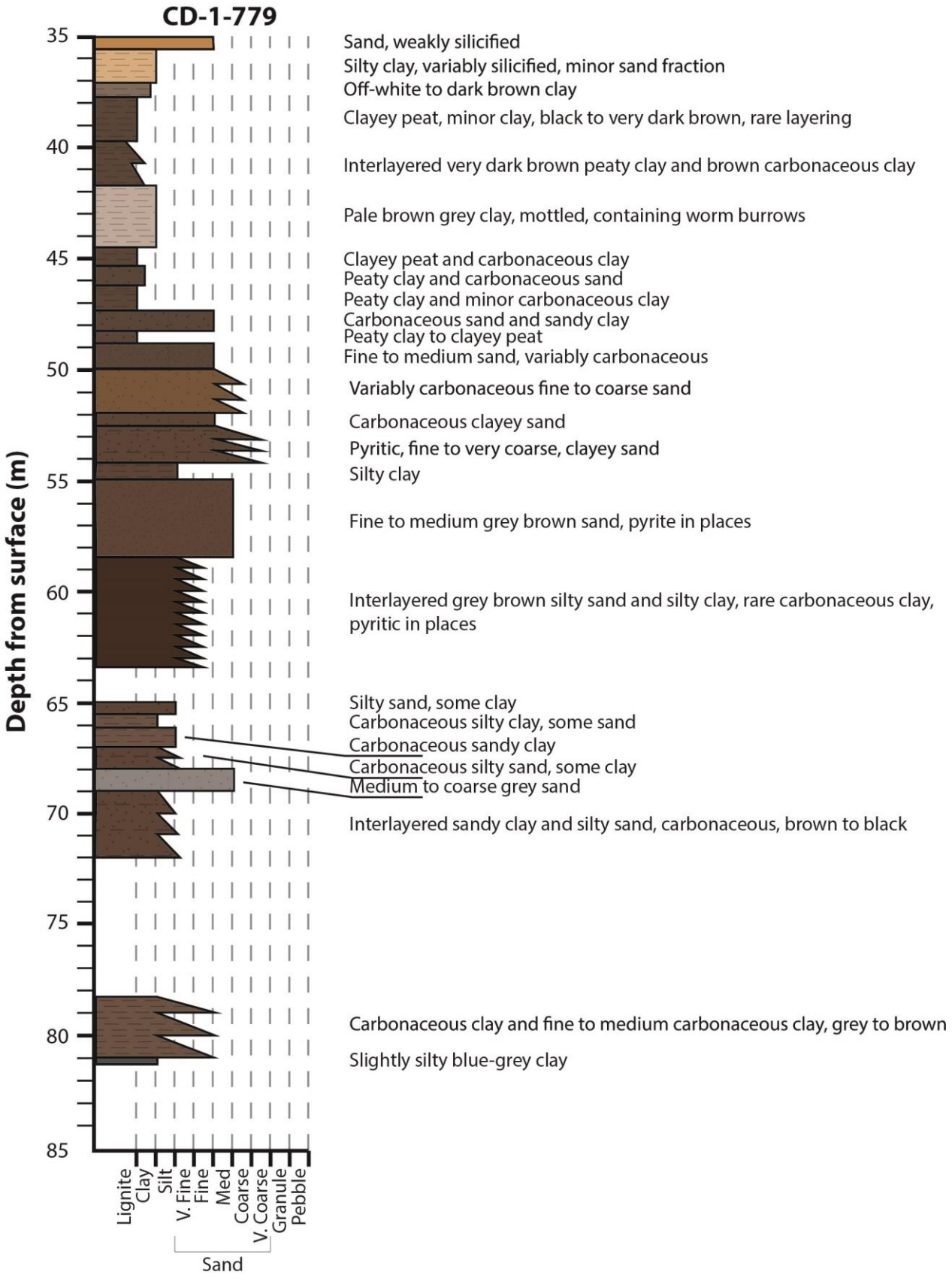

NNA-5738
Depth from surface (m)
45
50
55
60
65
70
75
80
85
90
Lignite
Clay
Silt
V. Fine
Fine
Med
Coarse
V. Coarse
Granule
Pebble
Sand
Light brown very fine-grained sandstone
Dark brown to black carbonaceous claystone
Black lignite
Dark brown to black sandy (40%) claystone (60%)
Dark brown to black, fine- to medium-grained, well-sorted sandstone
Light brown sandy claystone, sand content increasing with depth
Grey, medium-grained, well sorted sandstone
Grey sandy claystone
Pebble bed within grey sandy claystone

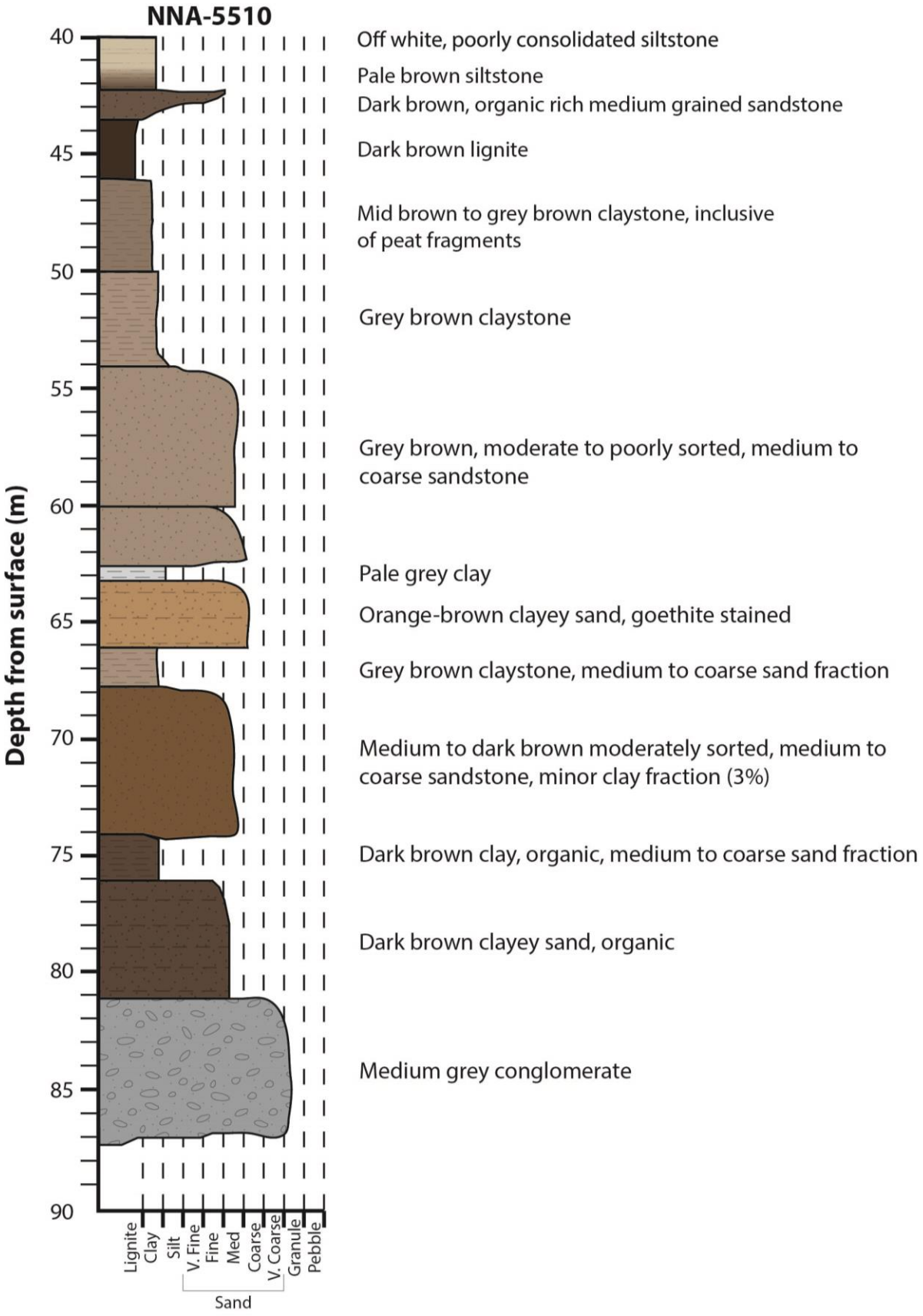

NND-5077
Depth from surface (m)
40
45
50
55
Cream, coarse grained arkose sand, sericitic clay
Dark brown/black lignite with interbedded lignitic clay
Dark brown clay with minor lignite
Dark brown lignite and clay, fossil wood
Light grey to dark brown, poorly sorted, carbonaceous sandstone
Lignite
Clay
Silt
V. Fine
Fine
Med
Coarse
V. Coarse
Granule
Pebble
Sand


NND-5028
Depth from surface (m)
35
40
45
50
55
60
White to light brown, interbedded clay and clayey, fine- to medium-grained sand
Interbedded lignite and dark brown lignitic clay
Black, carbonaceous, medium- to coarse-grained sand
Lignite
Black, medium- to coarse-grained carbonaceous sand, 20% clay
Dark brown, carbonaceous clay, 20% coarse sand
Two cycles of grey-black carbonaceous sand, with minor lignite and light grey clay interbeds
Brown grey, fining upwards cycles of medium/coarse-grained to fine-grained sand
Orange/white to dark grey medium-grained, well sorted sand
White/light grey, medium- to fine-grained sand, well sorted, fining upwards
Light grey, five fining upwards cycles of medium- to fine-grained sand
Orange to white, fining upwards, very coarse- to medium-grained sand
White, medium grained sand
Grey-brown to black, fining upwards medium- to fine-grained sand
Lignite
Clay
Silt
V. Fine
Fine
Med
Coarse
V. Coarse
Granule
Pebble
Sand


NNA-5507
Depth from surface (m)
40
45
50
55
60
65
70
75
80
85
90
Pale brown siltstone
Dark brown lignite
Dark brown coarse to medium sand, minor clay
Pale brown fining upwards sand with dark organic fraction
Pale brown fining upwards sand with dark organic fraction
Minor granules
Pebbles to 30 mm
Clayey very fine sand to sandy clay, pale grey
Lignite
Clay
Silt
V. Fine
Fine
Med
Coarse
V. Coarse
Granule
Pebble
Sand


NNA-5030
Depth from surface (m)
35
40
45
50
55
60
Dark brown to black lignite, with minor carbonaceous clay interbed at 35.6
Black/brown lignitic clay
Dark brown, mod. sorted, medium- to coarse-grained carbonaceous sand
Dark brown, mod. sorted, medium- to coarse-grained carbonaceous sand, fining upwards to lignitic clay
Dark brown lignitic clay
Light grey, mod. sorted, medium- to coarse-grained sand
Dark brown lignitic clay
Dark brown medium-grained sand
Brown, mod. to poorly sorted carbonaceous sand
Dark brown carbonaceous clay, interbeds of fine- and medium-grained sand
Brown/grey, well sorted, very fine-grained sand
Grey, well sorted, fine-grained sand
Dark grey, well sorted, very fine-grained carbonaceous sand
Light brown/grey, fine-grained carbonaceous sand, fining upwards, minor clay interbeds
Dark brown, carbonaceous clay with minor fine sand
Light brown grey fine sand, with minor silt and carbonaceous sand
Dark grey, poorly sorted carbonaceous sand
Medium grey, poorly sorted carbonaceous sand
Light grey, very coarse to very fine, carbonaceous sand, fining upwards
Light grey, medium sand with minor interval of fine-grained sand
Lignite
Clay
Silt
V. Fine
Fine
Med
Coarse
V. Coarse
Granule
Pebble
Sand


CD-1-779
Depth from surface (m)
35
40
45
50
55
60
65
70
75
80
85
Sand, weakly silicified
Silty clay, variably silicified, minor sand fraction
Off-white to dark brown clay
Clayey peat, minor clay, black to very dark brown, rare layering
Interlayered very dark brown peaty clay and brown carbonaceous clay
Pale brown grey clay, mottled, containing worm burrows
Clayey peat and carbonaceous clay
Peaty clay and carbonaceous sand
Peaty clay and minor carbonaceous clay
Carbonaceous sand and sandy clay
Peaty clay to clayey peat
Fine to medium sand, variably carbonaceous
Variably carbonaceous fine to coarse sand
Carbonaceous clayey sand
Pyritic, fine to very coarse, clayey sand
Silty clay
Fine to medium grey brown sand, pyrite in places
Interlayered grey brown silty sand and silty clay, rare carbonaceous clay, pyritic in places
Silty sand, some clay
Carbonaceous silty clay, some sand
Carbonaceous sandy clay
Carbonaceous silty sand, some clay
Medium to coarse grey sand
Interlayered sandy clay and silty sand, carbonaceous, brown to black
Carbonaceous clay and fine to medium carbonaceous clay, grey to brown
Slightly silty blue-grey clay
Lignite
Clay
Silt
V. Fine
Fine
Med
Coarse
V. Coarse
Granule
Pebble
Sand


NNA-5510
Depth from surface (m)
40
45
50
55
60
65
70
75
80
85
90
Off white, poorly consolidated siltstone
Pale brown siltstone
Dark brown, organic rich medium grained sandstone
Dark brown lignite
Mid brown to grey brown claystone, inclusive of peat fragments
Grey brown claystone
Grey brown, moderate to poorly sorted, medium to coarse sandstone
Pale grey clay
Orange-brown clayey sand, goethite stained
Grey brown claystone, medium to coarse sand fraction
Medium to dark brown moderately sorted, medium to coarse sandstone, minor clay fraction (3%)
Dark brown clay, organic, medium to coarse sand fraction
Dark brown clayey sand, organic
Medium grey conglomerate
Lignite
Clay
Silt
V. Fine
Fine
Med
Coarse
V. Coarse
Granule
Pebble
Sand

APPENDIX 8. Species distribution and percentage occurrence in eight drill holes, ordered by first appearance

Appendix Table 8.1 Species distribution and percentage occurrence in NNA-5605 (Princess). Percentages derived from 200-grain counts.

NNA-5605						
Depth	41.0-42.0	46.0-47.0	50.0-51.0	54.0-55.0	56.0-57.0	60.0-61.0
Lithological Interval	E3	E1	E1	Dc2	Dc1	Dc1
Species						
Cryptogam Spores						
Baculatisporites comaumensis	+					
Laevigatosporites ovatus	+	+	+	+	+	+
Cyathidites australis		+		+		
Gleicheniidites circinidites		+	+	+	+	+
Verrucatosporites speciosus			0.5			+
C. minor				+	+	
Latrobosporites marginis				0.5	+	
Gymnosperms						
Lygistepollenites florinii	1	3	3	2.5	1.5	1.5
Podocarpidites ellipticus	6	4	1	1.5	0.5	+
Phyllocladidites mawsonii		0.5	+	+		+
Trichotomosulcites subgranulatus		+		+		
Dacrycarpites australiensis			0.5	+		0.5
Angiosperms						
B. cooksonii	0.5	0.5	+		+	0.5
Beaupreaidites diversiformis	0.5				+	+
C. orthoteichus	0.5	+	+	0.5	+	0.5
C. reticularis	0.5			+		
P. cirritulis	0.5	1	+		0.5	+
P. narnooensis	0.5	0.5	0.5			+
R. microreticulatus	0.5				0.5	
Santalumidites cainozoicus	0.5		+	1	+	+
Tricolpites incisus	0.5	0.5	0.5	+	+	+
Tricolporites adelaidensis	0.5	+	+	+	+	+
T. prolata	0.5	1	+		1	1
Polycolporopollenites esobalteus	1		0.5	+		
Rhoipites angurium	1		+			+
R. minutiformis	1	1.5	2.5	4	5.5	9
T. scabratus	1		1	1	+	+
Tetracolporites palynius	1.5					
Tricolpites spp.	2.5	0.5			0.5	
Liliacidites aviemorensis	3		+	1.5		1.5
T. occultum	3	0.5				1
Proteacidites spp.	4	1.5	3	4	1.5	4.5
N. falcatus	4.5	4.5	4.5	2	5.5	3
M. mesonesus	5	4	3.5	1.5	10	11
Tricolporites spp.	8	0.5	3	2	6.5	3
Nothofagidites brachyspinulosus/incrassatus	10	9	11	2.5	1	3.5
Haloragacidites harrisii	18	16.5	13	18	12.5	12

NNA-5605						
Depth	41.0-42.0	46.0-47.0	50.0-51.0	54.0-55.0	56.0-57.0	60.0-61.0
Lithological Interval	E3	E1	E1	Dc2	Dc1	Dc1
Species						
N. emarcidus/heterus	22.5	43.5	44.5	45.5	42.5	39.5
Banksieaeidites arcuatus	+	2	1.5	+	0.5	+
B. verrucosus	+	+	+		+	
Bluffopollis scabratus	+					0.5
Ericipites scabratus	+	+	+	1	0.5	0.5
Gothanipollis bassensis	+			1	+	
Ilexpollenites anguloclavatus	+		+		+	0.5
Malvacipollis diversus	+	+	+	1.5	1	1
P. annularis	+	0.5	+	+	0.5	1
P. pachypolus	+	+	+	3.5	1	0.5
P. subscabratus	+					
P. symphyonemoides	+					
R. oralongii	+			+		
R. orbiculatus	+				+	
Sapotaceoidaepollenites rotundus	+	1	+	+	1	+
T. reticularis	+					
T. secarius	+					
N. senectus		0.5				
P. cf. *nitidus*		0.5			0.5	
M. eucalyptoides		1	+	1.5	1	0.5
Ailanthipites paenestriatus		+			+	+
P. crassus		+	+	+	+	
P. obscurus		+	1.5	+		
P. pseudomoides		+				
P. reticulatus		+	+	+	+	+
T. leuros		+	+	+	+	
Nothofagidites spp.			0.5			
Periporopollenites demarcatus			1.5	1.5	0.5	0.5
B. elegansiformis			+		+	
Myrtaceidites corymbiensis			+			
P. nasus			+	+	+	+
P. tesselaria			+			
R. goulburnensis			+	0.5	0.5	
Schizocolpus marlinensis			+			
C. major				+		+
P. carobelindiae				+		0.5
P. cumulus				+		
P. protrudens				+		
P. tuberculiformis				+	+	
Tetracolporopollenites sp. (Milne 1988, Plate 6 O)				+		
Rhoipites spp.					0.5	

NNA-5605						
Depth	41.0-42.0	46.0-47.0	50.0-51.0	54.0-55.0	56.0-57.0	60.0-61.0
Lithological Interval	E3	E1	E1	Dc2	Dc1	Dc1
Species						
T. thomasii					0.5	+
Anacolosidites acutullus					+	
B. davidsonii					+	
P. colubrimodus					+	
Psilastephanocolporites micus					+	+
R. ivanhoensis					+	
R. muehlenbeckiaformis					+	
T. simatus					+	
T. cf. *thomasii*					+	
B. minimus						+
Cupanieidites major						+
Proteacidites adenanthoides						+
P. aff. Grevillea						+
P. kopiensis						+
P. rickmanii						+
Triporopollenites ambiguus						+
Gen. *et*. sp. indet.	1.5	1.5	2.5	1.5	2.5	2.5
Total	100	100	100	100	100	100

Appendix Table 8.2 Species distribution and percentage occurrence in NNA-5738. Percentages derived from 200-grain counts.

NNA-5738					
Depth	49.0-50.0	52.0-53.0	59.0-60.0	61.0-62.0	64.0-65.0
Lithological Interval	E2	E2	E1	E1	E1
Species					
Cryptogam Spores					
Cyathidites australis	+			+	
C. minor		0.5	+		
Laevigatosporites ovatus			+	+	+
Verrucatosporites speciosus				+	+
Baculatisporites comaumensis					+
Monolites alveolatus					0.5
Gymnosperms					
Lygistepollenites florinii	1	0.5	0.5	0.5	+
Podocarpidites ellipticus	3.5		+	+	0.5
Phyllocladidites mawsonii	+	0.5			+
Dacrycarpites australiensis			0.5		+
Trichotomosulcites subgranulatus					+
Angiosperms					
Banksieaeidites arcuatus	0.5	0.5	1.5		+
B. cooksonii	0.5		+	+	+
Gothanipollis bassensis	0.5		1	+	+
Sapotaceoidaepollenites rotundus	0.5	1		+	+
Tricolpites spp.	0.5		0.5		
T. microreticulatus	0.5	0.5			
Tricolporites spp.	0.5	2	9.5	6.5	8
Cupanieidites orthoteichus	1		+		+
Ericipites scabratus	1			0.5	
Proteacidites spp.	1	6.5	1	4	2
Nothofagidites brachyspinulosis/incrassatus	1.5	1	1.5	4.5	4.5
P. annularis	1.5	2.5	+	0	+
Liliacidites aviemorensis	2	0.5	2	3.5	3
P. cirritulis	3.5	4	1	0.5	+
R. minutiformis	3.5	1	5.5		2
Malvacipollis diversus	4.5	7	3	2	2
N. falcatus	4.5	+	1.5	4	1
Haloragacidites harrisii	14.5	29.5	11	14.5	17
M. mesonesus	22	16.5	32.5	15	15.5
N. emarcidus/heterus	30	22.5	15	42	37.5
Ailanthipites paenestriatus	+		+	+	+
B. davidsonii	+			+	
Beaupreaidites diversiformis	+				
Myrtaceidites eucalyptoides	+		0.5	+	1
N. spinosus	+				
Periporopollenites demarcatus	+	0.5		+	0.5

NNA-5738					
Depth	49.0-50.0	52.0-53.0	59.0-60.0	61.0-62.0	64.0-65.0
Lithological Interval	E2	E2	E1	E1	E1
Species					
Polycolporopollenites esobalteus	+			+	
P. carobelindiae	+	+		+	+
P. obscurus	+		+	0.5	+
P. pachypolus	+	+		+	0.5
P. cf. *reticulatus*	+				
Psilastephanocolporites micus	+				
R. sphaerica	+				+
Triporopollenites ambiguus	+				
P. crassus		0.5			+
P. cf. *pseudomoides* sp. 3		+			
P. cf. *rynthius*		+			
R. microreticulatus		+		+	+
Tetracolporites palynius		+			
R. angurium			0.5	+	+
R. sp. A			0.5		
Santalumidites cainozoicus			0.5	+	+
T. reticularis			0.5		
B. verrucosus			1		
R. goulburnensis			1		+
T. scabratus			1.5		+
Myrtaceidites spp.			2		
Anacolosidites luteoides			+		
R. aralioides			+		
R. ivanhoensis			+		
Tricolpites incisus			+	0.5	+
Clavatipollenites glarius				0.5	1
Proteacidites adenanthoides				0.5	
A. mulleri				+	+
Bluffopollis scabratus				+	+
P. reticulatus				+	
T. cf. *phillipsii*				+	
T. thomasii				+	
T. angurium				+	
T. leuros				+	
P. aff. *Isopogon*					+
P. narnooensis					0.5
P. nasus					+
P. cf. *nitidus*					0.5
Rhoipites alveolatus					1
R. orbiculatus					+
Tricolporites adelaidensis					+

NNA-5738					
Depth	49.0-50.0	52.0-53.0	59.0-60.0	61.0-62.0	64.0-65.0
Lithological Interval	E2	E2	E1	E1	E1
Species					
T. prolata					0.5
Gen. *et* sp. indet.	1.5	2.5	4.5	0.5	1
Total	100	100	100	100	100

Appendix Table 8.3 Species distribution and percentage occurrence in NND-5077. Percentages derived from 200-grain counts.

	NND-5077										
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1
Species											
Cryptogam Spores											
Gleicheniidites circinidites	+	+	+	+			0.5		+	1.5	+
Laevigatosporites ovatus	+			+					1.5	+	
Latrobosporites marginis	+		+	+					+	+	
Verrucosisporites kopukuensis	+			+						+	
Cyathidites minor		0.5								+	
Cyathidites australis			1		+	+				+	
Verrucatosporites speciosus			+	+		+	+			+	
Rugulatisporites sp.					+						
Dictyophyllidites equiexinus						+					
Spore sp. B										+	+
Cyathidites spp.											
Gymnosperms											
Phyllocladidites mawsonii	0.5	1	1	0.5	3	1.5	2.5		+		+
Lygistepollenites florinii	1	2	3	1.5	2	5.5	7.5	0.5	6.5	1.5	2.5
Podocarpidites ellipticus	1	3	0.5	0.5	2	4	4.5		2.5	1	0.5
Trichotomosulcites subgranulatus		0.5		0.5			0.5	0.5			
Parvisaccites catastus			+		+				+		
Dacrycarpites australiensis					+	+	0.5	+	0.5		
Angiosperms											
Banksieaeidites arcuatus	0.5	+	1	1	0.5	+	+		+		+
Gothanipollis bassensis	0.5	0.5	0.5	+	0.5			0.5		0.5	+

NND-5077											
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1
Species											
R. ivanhoensis	0.5	+					+	+			
R. microreticulatus	0.5							2			
Schizocolpites marlinensis	0.5		0.5								
Malvacipollis diversus	1	1	+	0.5	1		+	1	1	0.5	
P. cirritulis	1	2.5	+		1	2	+	1	+	1.5	0.5
T. prolata	1	1	0.5	1.5	+	1.5	0.5	1.5	1.5		
M. eucalyptoides	1.5	0.5	2		1		0.5		1	0.5	+
Rhoipites angurium	1.5	+	1	+		+		7	1	+	
Nothofagidites brachyspinulosus/incrassatus	2.5		5.5	3.5	2		4.5	6.5	+	1	0.5
Proteacidites spp.	3	2	2	4.5	2	1	2.5	15	1.5	4.5	0.5
R. minutiformis	3	1.5	3.5	2.5	2.5	0.5	1		0.5	3.5	2
Tricolporites spp.	4.5	1	4.5	6.5	1.5	1	1.5	2.5	5	4	2.5
N. falcatus	5	3	4	3.5	1	1.5	5.5		4	6.5	7.5
Haloragacidites harrisii	12	10.5	12.5	17	14.5	12.5	18.5	6	28.5	12	9.5
M. mesonesus	12.5	11.5	11	1.5	10.5	6.5	6.5	9.5		7.5	1.5
N. emarcidus/heterus	45	51.5	42.5	49	50.5	56	36.5	41	40.5	47.5	68.5
A. paenestriatus	+		+	+	+		+			+	+
Beaupreaidites diversiformis	+		+	+		+					
B. verrucosus	+		+	+	+					+	
Bluffopollis scabratus	+	0.5	+	+	+	+	1.5				
Ericipites scabratus	+	+		+	0.5	+	0.5		0.5	+	+
N. senectus	+	+	+		+			+			+
Periporopollenites demarcatus	+		+		+			+		+	+

NND-5077											
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1
Species											
P. annularis	+	0.5	0.5	1	0.5	2	1	1	+	2	1
P. carobelindiae	+	+	+	+	0.5	+	+		+	+	+
P. crassus	+	+	+	+						+	+
P. crochetaria	+			+	+						
P. aff. *Isopogon*	+			+			0.5			0.5	
P. cf. *nitidus*	+		1								
P. obscurus	+	+	+	+			+		1	0.5	+
P. pachypolus	+	+		+	+		+	+	0.5		
P. reticulatus	+	0.5	+	+	0.5	+	+			+	+
P. rynthius	+									+	
P. cf. *stipplatus*	+										
P. tenuiexinus	+										
Psilastephanocolporites micus	+			0.5	+					+	
Sapotaceoidaepollenites rotundus	+		+		+	0.5	0.5	1.5		+	
Tetracolporites palynius	+								+		+
T. simatus	+									+	
Tricolporites adelaidensis	+				+				0.5	+	+
T. leuros	+	1.5	+	+		+	0.5		0.5	0.5	+
Triporopollenites ambiguus	+	+			+	+				+	
R. sphaerica		0.5	0.5		1	+		+			
Liliacidites aviemorensis		1			1	1.5				1	
B. elegansiformis		+		+	+		+		+	+	+
P. sp. B Milne 1988		+		+							

NND-5077											
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1
Species											
P. cumulus		+	+	+	+	+	+			+	+
Tetracolporopollenites sp. (Milne 1988)		+								+	+
R. goulburnensis			0.5								
T. occultum			0.5	0.5		0.5		0.5			
B. cooksonii			+	+	+						+
Proteacidites adenanthoides			+	+		+					
P. tesselaria			+	+						+	
Polycolporopollenites esobalteus				1				0.5			+
Cupanieidites major				+							
P. cf. *P. reticulatus*				+							
T. scabratus				+	+		1	+	0.5		
Anacolosidites acutullus					+						
B. davidsonii					+		+		0.5	+	+
C. orthoteichus					+	0.5					
C. reticularis					+						
Myrtaceidites corymbiensis					+		+				
P. narnooensis					+						
P. punctiporus					+						
P. sp. E					+						+
Ilexpollenites anguloclavatus						0.5	1	2		+	
T. robustus						1					
P. sp. I						+					
T. delicatus						+					

NND-5077											
Depth	51.1	51.3	51.5	51.7	51.9	52.1	52.3	52.5	52.7	53.7	53.9
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E1	E1
Species											
P. pseudomoides							+			0.5	
Ailanthipites mulleri								+			+
Santalumidites cainozoicus								+		0.5	+
Tricolpites spp.										0.5	1.5
P. nasus										+	+
P. rickmanii										+	+
P. scitus										+	
Tricolpites sp. B										+	
Tricolpites incisus											0.5
Arecipites waitakiensis											+
Propylipollis sp. A Milne 1988											+
P. confragosus											+
R. cissus											+
R. orbiculatus											+
Gen. *et*. sp. indet.	1.5	2	0.5	3	0.5				0.5	0.5	1
Total	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 8.4 Species distribution and percentage occurrence in NND-50287. Percentages derived from 200-grain counts

	NND-5028													
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E3	E3	Dw3
Species														
Cryptogam Spores														
Cyathidites australis		+		+	+		+						0.5	
Gleicheniidites circinidites		+		1	+							+	+	
Verrucatosporites speciosus		+										+	+	
Laevigatosporites ovatus				+	0.5		0.5		+	+	0.5			
Baculatisporites comaumensis						1.5								
C. minor										+		+	+	
Peromonolites vellosus													+	
Spore spp.													+	
Gymnosperms														
Podocarpidites ellipticus	2	3	2.5	1	7.5	5	4	2.5	5	1.5	2		+	+
P. puteus	+													
Lygistepollenites florinii		6	+	1	1.5	1	2	0.5	+		2	2	0.5	1
Parvisaccites catastus			0.5		+		+							
Dacrycarpites australiensis				0.5	0.5		+						+	0.5
Phyllocladidites mawsonii							+		1				+	+
Trichotomosulcites subgranulatus										+	0.5		0.5	
Angiosperms														
N. falcatus	0.5	1.5	+		+	+	0.5	+		1.5	3	1	+	3.5
Polycolporopollenites esobalteus	0.5	0.5	0.5	0.5	+		0.5						0.5	
R. angurium	0.5	0.5	1.5	5	1.5		4.5	0.5	0.5	0	+	2.5	1.5	+

NND-5028														
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E3	E3	Dw3
Species														
Sapotaceoidaepollenites rotundus	0.5	+	+	+	+	0.5	1	+	+	0.5		+	+	
Tricolpites spp.	0.5			2	1							0.5		
Liliacidites aviemorensis	1	0.5	2	1.5	2	1.5	1	+	0.5	0.5	0.5		0.5	1
P. cirritulis	1.5	5	0.5	+	1.5	1.5	1		+		0.5	0.5		
Proteacidites spp.	1.5	7	1	0.5	0.5		5	1.5	1.5	2.5	1	2.5	4.5	
T. occultum	2			1			0.5		1	2.5		0.5	+	+
M. mesonesus-parvus	2.5	9.5	11	23	33	53	22	41.5	23	11.5	9.5	6.5		
Tricolporites spp.	6.5	6	8.5	13	10	4	7	3.5	5	2	2	5.5	7.5	0.5
Malvacipollis diversus	10	18.5	10.5	4.5	1	1		+	1.5	0.5	0.5	2	0.5	0.5
N. emarcidus/heterus	12.5	11.5	13.5	9	8.5	4.5	13	17	20.5	17.5	22.5	32	65	81
Haloragacidites harrisii	55.5	17.5	40	12.5	7	2.5	8.5	6	11.5	25	35	26	7	4
B. davidsonii	+						+		+	3.5				
C. reticularis	+													
Santalumidites cainozoicus	+	1	0.5	1			+	0.5					+	
Banksieaeidites arcuatus		0.5		5	2	1.5	1.5	1	+	1	0.5	1.5	1.5	+
P. ambassadatus		0.5												
P. microspinosus		0.5												
P. pachypolus		0.5	+	+		+	0.5	+		+		+		0.5
T. prolata		0.5	0.5		2.5	5.5	5	0.5	2.5	6	3	3	0.5	
T. cf. *thomasii*		1								+				
R. minutiformis		2	2	8.5	6.5	2	13	5.5	4.5	7	1.5	1	4	2.5
Nothofagidites brachyspinulosus/incrassatus		2.5	2	1		1		6	5	4.5	6.5	6	+	1.5
P. crassus		2.5												

NND-5028														
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E3	E3	Dw4
Species														
Ailanthipites mulleri		+								+				
B. cooksonii		+					+		2.5	3.5	0.5			
Beaupreaidites diversiformis		+	+	+	+	+					+			
B. verrucosus		+					1	+				+		
Periporopollenites demarcatus		+		0.5			+						+	+
P. cf. *grandis*		+												
P. protrudens		+												
P. rynthius		+									0.5			
Tetracolporites palynius		+						+				+	+	
T. reticularis			0.5	0.5			+	+						
A. paenestriatus			+				+	+			+	+	+	+
Arecipites waitakiensis			+											
B. elegansiformis			+	+	+	+	+		+				+	
Bluffopollis scabratus			+								+	+	+	
Cupanieidites major			+				+						+	
Gothanipollis bassensis			+		0.5	+	0.5	3	0.5					+
I. verrucatus			+											
P. confragosus			+											
Psilastephanocolporites micus			+	+	0.5		0.5							+
Rhoipites alveolatus			+	+	0.5		0.5		+					
R. ivanhoensis			+		+	0.5	+			0.5	+			
Tetracolporopollenites sp. Milne 1988			+											
Ericipites scabratus				0.5			+						1	1.5

NND-5028														
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E3	E3	Dw3
Species														
R. microreticulatus				1		+				0.5	1.5			
T. incisus				1		0.5		0.5	0.5				+	+
R. sphaerica				1	+		0.5	1.5	1					
Propylipollis cf. robustus				+										
P. cumulus				+			+					0.5		
R. cissus				+	+	+	+		+					
T. secarius				+	0.5									
Tricolporites adelaidensis				+		+					0.5	0.5	+	
Tricolporites sp. A				+										
Rhoipites spp.					1									
T. leuros					1	0.5	+		0.5	1		+	+	+
R. goulburnensis					2	0.5	1		0.5				+	
M. eucalyptoides					2.5	6	+	4.5	10	2	2.5	1.5	1.5	1.5
Anacolosidites luteoides					+	1.5	+	0.5						
C. orthoteichus					+			+						
R. aralioides					+									
T. cf. *phillipsii*					+								2	
T. simatus					+									
T. scabratus					+	+	2	1.5	1	1	0.5	0.5		
Triporopollenites vargus					+									
Ilexpollenites anguloclavatus						0.5			+					+
Schizocolpites marlinensis						0.5								
P. pseudomoides							1							

NND-5028														
Depth	39.1	39.6	40.5	41.5	42.2	43	43.6	44.1	45	45.8	46.3	48.2	48.4	58.3
Lithological Interval	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2	E3	E3	Dw3
Species														
Myrtaceidites corymbiensis							+							+
P. crochetaria							+							
T. thomasii							+							+
Tricolpites sp. A							+							
P. nasus								+	+			+		
P. annularis									+			0.5	+	
Tricolpites confessus									+			0.5		
P. reticulatus											+		+	+
Proteacidites adenanthoides												+		
P. aff. *Grevillea*												+		
P. narnooensis												+		
P. obscurus												+		
P. aff. *Isopogon*													+	
Sparganiaceaepollenites barungensis														0.5
P. carobelindiae														+
P. leightonii														+
P. cf. *reticulatus*														+
P. subscabratus														+
Gen. *et*. sp. indet.	1.5	1.5	2.5	4	4.5	3.5	2	2		3.5	3	3	1	
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 8.5 Species distribution and percentage occurrence in NNA-5507. Percentages derived from 200-grain counts

NNA-5507				
Depth	47.0-48.0	52.0-53.0	54.0-55.0	59.0-60.0
Lithological Interval	E2	E1	E1	Dw3
Species				
Spores				
Cyathidites australis	+			
Verrucatosporites speciosus	+	+	+	
Cyathidites sp.		+		
Laevigatosporites ovatus		+		+
Gleicheniidites circinidites				+
Gymnosperms				
Lygistepollenites florinii	2	2	4	+
Podocarpidites ellipticus	4.5	6	3	1
Trichotomosulcites subgranulatus	+			
Dacrycarpites australiensis		0.5	0.5	
Parvisaccites catastus		0.5		
Phyllocladidites mawsonii		+	+	+
Podocarpidites spp.				0.5
Angiosperms				
P. carobelindiae	0	+		+
Cupanieidites orthoteichus	0.5	+	+	
Liliacidites aviemorensis	0.5	0.5	1	
P. annularis	0.5	0.5	+	+
P. cirritulis	0.5	0.5	1	1.5
P. tesselaria	0.5			
T. thomasii	0.5			
Periporopollenites demarcatus	1	+		1.5
R. microreticulatus	1	1		0.5
T. occultum	1.5			0.5
Malvacipollis diversus	2.5	1	0.5	0.5
Tricolporites spp.	3.5	9	3.5	3.5
Proteacidites spp.	4	2.5	4.5	5
R. minutiformis	6.5	4.5	2	4
Nothofagidites brachyspinulosis/incrassatus	8.5	5	5	5
Haloragacidites harrisii	10	6.5	11	1.5
N. emarcidus/heterus	24.5	31	50	38
M. mesonesus/parvus	26.5	12	6.5	14
Ailanthipites paenestriatus	+	+	+	0
Banksieaeidites arcuatus	+	2	0.5	3
B. cooksonii	+	+	0.5	+
Proteacidites adenanthoides	+			
P. ambassadatus	+			
P. crassus	+			0.5

NNA-5507				
Depth	47.0-48.0	52.0-53.0	54.0-55.0	59.0-60.0
Lithological Interval	E2	E1	E1	Dw3
Species				
R. hawkdunensis	+			
Santalumidites cainozoicus	+	+	+	+
Sapotaceoidaepollenites rotundus	+	+	0.5	+
Tetracolporites palynius	+		0.5	0.5
T. leuros	+	+	+	+
T. scabratus	+	+		
Ilexpollenites anguloclavatus		0.5		
Myrtaceidites eucalyptoides		0.5	+	0.5
Psilastephanocolporites micus		0.5		1.5
R. cissus		0.5		
Tricolpites confessus		0.5		
P. narnooensis		1	1	
Rhoipites angurium		1	+	0.5
R. goulburnensis		1		+
T. incisus		1	+	0.5
Tricolpites spp.		1	0.5	2
T. prolata		1.5		
N. falcatus		4	1.5	3.5
Beaupreaidites diversiformis		+		+
B. verrucosus		+	+	+
Bluffopollis scabratus		+		+
Ericipites scabratus		+	+	0.5
P. cumulus		+		
P. pachypolus		+	+	5
P. reticulatus		+	+	+
Tricolporites adelaidensis		+		+
B. davidsonii			+	
P. obscurus			+	0.5
R. fragilis			+	
R. orbiculatus			+	
Anacolosidites acutullus				0.5
Myrtaceidites spp.				1
Polycolporopollenites esobalteus				+
P. nasus				+
P. rynthius				0.5
Gen *et*. sp. indet.	1	2	2.5	2.5
Total	100	100	100	100

Appendix Table 8.6 Species distribution and percentage occurrence in NND-5030. Percentages derived from 200-grain counts

NND-5030							
Depth	37.2	41.6	42.2	46.2	51.3	58.2	61.8
Lithological Interval	E2	E2	E2	Dc3	Dc2	Dw3	Dw3
Species							
Cryptogam Spores							
Laevigatosporites ovatus	+	0.5		+	+	+	0.5
Cyathidites australis		+					
Gleicheniidites circinidites				+	0.5		
Latrobosporites marginis				+			
Verrucatosporites speciosus					+		
Peromonolites vellosus						+	
Cyathidites minor							+
Cyathidites sp.							0.5
Gymnosperms							
Lygistepollenites florinii	0.5	2.5	2	3.5	2	0.5	0.5
Dacrycarpites australiensis	1.5	0.5			0.5		
Parvisaccites catastus		+					
Podocarpidites spp.		5.5					
Podocarpidites ellipticus		6	1.5	2	3.5	2	1
Trichotomosulcites subgranulatus			0.5				+
Phyllocladidites mawsonii				+	1		
Angiosperms							
B. verrucosus	0.5	+					
C. orthoteichus	0.5		+		1.5	2	0.5
P. cirritulis	0.5	+	1		+	1.5	1
P. cf. *nitidus*	0.5	0.5					
P. pachypolus	0.5	+	+		+	4	1
Rhoipites alveolatus	0.5						
Sapotaceoidaepollenites rotundus	0.5	+		+	1.5	+	0.5
Tricolpites incisus	0.5			+	1.5		0.5
T. scabratus	0.5	1	0.5	+			
A. luteoides	1						
R. goulburnensis	1		+	0.5	+	+	0.5
T. occultum	1	0.5	3.5				
Banksieaeidites arcuatus	1.5	+		1.5	0.5	+	0.5
Malvacipollis diversus	1.5	+	4.5	1	2	1.5	
Tricolpites spp.	2	0.5			0.5	1	
Proteacidites spp.	3	1.5	3.5	4.5	0.5	1.5	2.5
Liliacidites aviemorensis	3.5	1	1		0.5	0.5	1
N. emarcidus/heterus	4.5	18.5	16.5	32.5	37	46.5	29
T. prolata	5	1.5		1.5	3	0.5	0.5
Haloragacidites harrisii	6.5	14.5	29.5	22	12	3	6.5
Tricolporites spp.	7.5	4.5	2.5	10	6	3.5	2.5
R. minutiformis	8.5	7	10.5	4	4.5	2.5	7

NND-5030							
Depth	37.2	41.6	42.2	46.2	51.3	58.2	61.8
Lithological Interval	E2	E2	E2	Dc3	Dc2	Dw3	Dw3
Species							
M. mesonesus-parvus	44.5	24	16	2.5	11	24	31.5
Ailanthipites paenestriatus	+	+	+	+	+	+	
B. elegansiformis	+			+			
Ericipites scabratus	+		+				
Ilexpollenites anguloclavatus	+					0.5	
M. eucalyptoides	+	0.5	+	0.5	0.5	0.5	1.5
Nothofagidites brachyspinulosus/incrassatus	+	1.5	3	2.5	2.5	1	2
Polycolporopollenites esobalteus	+	+		0.5			
Propylipollis cf. *robustus*	+						
P. crassus	+		+		+		+
P. crochetaria	+						
P. rynthius	+						
Schizocolpites marlinensis	+						
T. spp. (Milne 1988)	+						
T. phillipsii	+						
T. reticularis	+						
C. reticularis		1					1
Gothanipollis bassensis		1			+		1
N. falcatus		1	1	1	2.5	0.5	1
B. cooksonii		2.5	1.5	1	+		
B. davidsonii		+	+				
P. reticulatus		+			+		
Psilastephanocolporites micus		+	+		0.5	0.5	+
R. oralongii		+					
T. simatus		+					
T. thomasii		+			+		
T. leuros		+			+		
R. sphaerica		+			0.5	+	+
P. narnooensis			0.5				
R. microreticulatus			0.5	0.5			0.5
Beaupreaidites diversiformis			+				+
P. cf. *leightonii*			+		+		
P. cf. *reticulatus*			+				
Rhoipites angurium			+	3.5	0.5	0.5	1.5
R. ivanhoensis			+	0.5	+		+
Santalumidites cainozoicus			+				
Anacolosidites acutullus				0.5			0.5
Myrtaceidites corymbiensis				0.5			0.5
P. annularis				0.5	+	+	+
N. senectus				+		+	
P. ivanhoensis				+			
R. cissus				+	+		

NND-5030							
Depth	37.2	41.6	42.2	46.2	51.3	58.2	61.8
Lithological Interval	E2	E2	E2	Dc3	Dc2	Dw3	Dw3
Species							
Tricolporites adelaidensis				+	0.5	+	
Bluffopollis scabratus					+		+
Periporopollenites demarcatus					+	1.5	1
Proteacidites ambassadatus					+		
P. carobelindiae					+	+	
P. aff. *Isopogon*					+		
P. nasus					+	+	
P. obscurus					+		
P. sp. H					+		
R. fragilis					+		
R. orbiculatus					+		+
Tetracolporites palynius					+		
Cupanieidites major						+	
L. variegatus						+	
P. pseudomoides							+
Gen. *et*. sp. indet.	2.5	2.5	0.5	3	3	0.5	2
Total	100	100	100	100	100	100	100

Appendix Table 8.7 Species distribution and percentage occurrence in CD-1-779. Percentages derived from 200-grain counts

CD-1-779					
Depth	39.9-40.0	44.9-45.0	65.5-65.6	71.2-71.3	80.9-81.0
Lithological Interval	E3	E2	Dc2	Dc2	Dc2
Species					
Spores					
Laevigatosporites ovatus	0.5		0.5	+	0.5
Neoraistrickia cf. *levidensis*	+				+
Latrobosporites marginis		0.5	+		
Verrucatosporites speciosus		+			
Cyathidites australis			0.5	+	+
Baculatisporites comaumensis			+	+	1
C. minor			+	+	
Gleicheniidites circinidites			+		
Verrucosisporites cristatus			+	+	
Dictyophyllidites equiexinus				+	
Gymnosperms					
Podocarpidites ellipticus	0.5	3	+	2	1
Lygistepollenites florinii	+	0.5	1	+	1
Parvisaccites catastus	+	+			
Dacrycarpites australiensis		0.5			
Trichotomosulcites subgranulatus		+			
Phyllocladidites mawsonii			0.5	0.5	
Angiosperms					
Ilexpollenites megagemmatus	0.5				
C. reticularis	1	+		+	0.5
Liliacidites aviemorensis	1	0.5		0.5	
M. subtilis	1			0.5	
P. pachypolus	1	+	1.5	+	0.5
Gothanipollis bassensis	1.5		+	0.5	
Proteacidites spp.	1.5	1	3	2.5	
Tricolporites spp.	1.5	3.5	7.5	4.5	0.5
R. minutiformis	2	5.5	2	2	
M. eucalyptoides	3	3		0.5	
Sapotaceoidaepollenites rotundus	4.5	0.5	+	+	1.5
Haloragacidites harrisii	5	14.5	4	9.5	5.5
Nothofagidites brachyspinulosus/incrassatus	6	13.5	11	11	8
N. emarcidus/heterus	6.5	13	15.5	16	26
Malvacipollis diversus	13	2	0.5	+	1
M. mesonesus/parvus	48	32	33	36.5	32
Ailanthipites paenestriatus	+		0.5		
Banksieaeidites arcuatus	+	0.5	1	0.5	
C. orthoteichus	+		1.5	1	1
Ericipites scabratus	+		0.5	+	

CD-1-779					
Depth	39.9-40.0	44.9-45.0	65.5-65.6	71.2-71.3	80.9-81.0
Lithological Interval	E3	E2	Dc2	Dc2	Dc2
Species					
Periporopollenites demarcatus	+	+	0.5	4	1
Polycolporopollenites esobalteus	+		+	+	
P. cirritulis	+	1		2	1.5
P. confragosus	+		+	+	
P. crochetaria	+				
P. nasus (small)	+		+		
P. cf. *notredamus*	+				
P. ornatus	+				
P. polygonalis	+				
P. protrudens	+				
P. reticulatus	+	+	+	+	
Psilastephanocolporites micus	+			1	
Rhoipites alveolatus	+		+	+	+
R. angurium	+	+	1	0.5	1
R. microreticulatus	+		+	+	1
Tetracolporites spp.	+	+			
Tricolpites incisus	+		0.5	+	1
T. occultum	+		2.5	+	
Tricolpites spp.	+		+		
N. falcatus		1.5	0.5		0.5
N. vansteenisii		1.5	2.5	1	3
B. cooksonii		+		+	+
B. davidsonii		+			+
Beaupreaidites diversiformis		+	+	+	
P. ambassadatus		+			
P. annularis		+	0.5	+	1.5
P. carobelindiae		+	+	+	
P. crassus		+	2	1.5	
P. cumulus		+			+
P. microspinosus		+	+		
P. narnooensis		+			
P. obscurus		+	+	+	
P. cf. *reticulatus*		+			
P. subscabratus		+			
P. tesselaria		+			
P. vaga		+			+
R. fragilis		+	+		
R. hawkdunensis		+			
R. ivanhoensis		+	0.5		1
R. cf. *muehlenbeckiaformis*		+			
R. orbiculatus		+			

CD-1-779					
Depth	39.9-40.0	44.9-45.0	65.5-65.6	71.2-71.3	80.9-81.0
Lithological Interval	E3	E2	Dc2	Dc2	Dc2
Species					
Santalumidites cainozoicus		+		+	1
Tetracolporites palynius		+			
T. simatus		+			
T. thomasii		+			
Tricolporites adelaidensis		+			
T. leuros		+			0.5
T. scabratus		+			
R. sphaerica		+	0.5		
Myrtaceidites corymbiensis			1.5	+	1
Anacolosidites acutullus			+	+	
Bluffopollis scabratus			+	+	
Cupanieidites major			+		
P. colubrimodus			+	+	+
P. leightonii			+		
P. cf. *nexinus*			+		
P. rectomarginis			+		
P. rynthius			+		+
R. cissus			+		
R. goulburnensis			+		+
Triporopollenites ambiguus			+		
P. cf. *nitidus*				0.5	
Schizocolpus marlinensis				0.5	+
P. pseudomoides				+	
L. variegatus					0.5
Propylipollis biporous					+
P. cf. *robustus*					+
Proteacidites adenanthoides					0.5
Rhoipites spp.					0.5
P. cf. *pseudomoides* sp. 1					1
P. sp. C					2
P. rectus					+
T. prolata					+
T. apiculatus					+
Gen *et*. sp. indet.	2	2	3.5	1	1.5
Total	100	100	100	100	100

Appendix Table 8.8 Species distribution and percentage occurrence in NNA-5510. Percentages derived from 200-grain counts

NNA-5510					
Depth	43.0-44.0	44.0-45.0	45.0-46.0	74.0-75.0	78.0-79.0
Lithological Interval	E2	E2	E2	Dc2	Dc2
Species					
Spores					
Cyathidites australis	+				
Gleicheniidites circinidites	+	0.5			
Laevigatosporites ovatus	+	1		0.5	
Baculatisporites comaumensis		0.5			
C. minor			0.5		
Verrucatosporites speciosus				+	
Gymnosperms					
Parvisaccites catastus	0.5	+			
Trichotomosulcites subgranulatus	0.5	0.5		0.5	
Lygistepollenites florinii	5	2.5	4	0.5	+
Podocarpidites ellipticus	6	7	5	0.5	+
Dacrycarpites australiensis	+	0.5	0.5	0.5	
P. puteus	+				
Phyllocladidites mawsonii		0.5	0.5	2.5	
Angiosperms					
Bluffopollis scabratus	0.5	+	+		
Gothanipollis bassensis	0.5	1	0.5		+
Malvacipollis diversus	0.5	2	6.5	0.5	0.5
Myrtaceidites eucalyptoides	0.5	1	0.5		1
Psilastephanocolporites micus	0.5				
R. angurium	0.5	1	0.5	3	+
Santalumidites cainozoicus	0.5	+	+		0.5
T. prolata	0.5		0.5		1
Banksieaeidites arcuatus	1		+	2	2.5
N. falcatus	1	0.5	0.5	1.5	2.5
Periporopollenites demarcatus	1	+		+	1
P. cirritulis	1	3	1.5	0.5	2
Sapotaceoidaepollenites rotundus	1.5	0.5	+	+	+
T. occultum	2	1	1		
P. narnooensis	2.5	2		+	
Nothofagidites brachyspinulosus/incrassatus	3.5	3	7.5	18.5	13.5
B. cooksonii	4.5	4		+	
Proteacidites spp.	4.5	2.5	0.5	2.5	1.5
R. minutiformis	6	4	3.5	7.5	1.5
Tricolporites spp.	7.5	6	4		
N. emarcidus/heterus	10.5	9.5	30	23.5	26.5
Haloragacidites harrisii	11	9	14.5	1.5	7.5
M. mesonesus/parvus	25	28.5	14	13	20

NNA-5510					
Depth	43.0-44.0	44.0-45.0	45.0-46.0	74.0-75.0	78.0-79.0
Lithological Interval	E2	E2	E2	Dc2	Dc2
Species					
Ailanthipites mulleri	+		+		
A. paenestriatus	+		+	1	1.5
B. davidsonii	+	0.5			
B. verrucosus	+			+	+
P. crassus	+		+	+	0.5
P. nasus	+		+		
P. pachypolus	+	+	0.5	2	2.5
P. reticulatus	+				
R. rotundiformis	+				
Tricolpites incisus	+	0.5	+	+	+
T. thomasii	+	+			
T. leuros	+		+	0.5	+
T. scabratus	+	+			
Anacolosidites luteoides		0.5	+		
P. rynthius		0.5			
R. microreticulatus		0.5			3
Schizocolpus marlinensis		0.5		0.5	+
R. oralongii		1			
Liliacidites aviemorensis		3		+	+
Polycolporopollenites esobalteus		+		+	+
P. carobelindiae		+			+
P. confragosus		+	+		
Tricolporites adelaidensis		+			
Beaupreaidites diversiformis			+		
P. cf. *pseudomoides* sp. 2			0.5		
R. ivanhoensis			+		+
Tetracolporites palynius			+		
P. ivanhoensis				0.5	
P. obscurus				0.5	1
P. vaga				0.5	0
Rhoipites spp.				0.5	0.5
T. reticularis				0.5	
Tricolpites spp.				0.5	
C. reticularis				1	1
Ilexpollenites anguloclavatus				1	+
P. nasus (small)				1	
R. sphaerica				1	1
Ericipites scabratus				1.5	0.5
Proteacidites annularis				1.5	2.5
R. goulburnensis				1.5	0.5
P. cf. *pseudomoides* sp. 1				4	

NNA-5510					
Depth	43.0-44.0	44.0-45.0	45.0-46.0	74.0-75.0	78.0-79.0
Lithological Interval	E2	E2	E2	Dc2	Dc2
Species					
C. orthoteichus				+	+
N. senectus				+	+
N. vansteenisii				+	
Propylipollis cf. robustus				+	+
P. leightonii				+	
P. microverrucatus				+	
P. polygonalis				+	
P. tenuiexinus					0.5
P. pseudomoides					2
Rhoipites alveolatus					+
Gen. *et*. sp. indet	1.5	1.5	3	1.5	1.5
Total	100	100	100	100	100

APPENDIX 9. List of species identified at Mulga Rock with describing authors

Species	Author
Cryptogam spores	
Baculatisporites comaumensis	(Cookson) Potonié 1956
Cibotiidites tuberculiformis	(Cookson) Skarby 1974
Cyathidites australis/minor	Couper 1953
Dictyophyllidites equiexinus	(Couper) Dettmann 1963
Gleicheniidites circinidites	(Cookson) Dettmann 1963
Laevigatosporites ovatus	Wilson & Webster 1946
Latrobosporites marginis	Mildnehall & Pocknall 1989
L. ohaiensis	(Couper) Stover in Stover & Partridge 1973
Monolites alveolatus	(Couper) Pocknall & Mildenhall 1984
Neoraistrickia cf. *levidensis*	(Balme) Backhouse 1988
Peromonolites vellosus	Partridge in Stover & Partridge 1973
Punctatosporites cf. *scabratus*	(Couper) Norris 1965
Rugulatisporites micraulaxus	Partridge in Stover & Partridge 1973
Verrucatosporites speciosus	Harris 1965
Verrucosisporites cristatus	Stover & Partridge 1973
V. kopukuensis	(Couper) Stover in Stover & Partridge 1973
Gymnosperms	
Dacrycarpites australiensis	Cookson & Pike 1953
Lygistepollenites florinii	(Cookson & Pike) Stover & Evans 1973
Parvisaccites catastus	Partridge in Stover & Partridge 1973
Phyllocladidites mawsonii	(Cookson) Couper 1953
Podocarpidites ellipticus	(Cookson) Couper 1953
P. puteus	Mildenhall & Pocknall 1989
Trichotomosulcites subgranulatus	Couper 1953
Angiosperms	
Monocolpate-Monosulcate-Monoporate	
Aglaoreidia qualumis	Partridge in Stover & Partridge 1973
Arecipites subverrucatus	(Pocknall) Mildenhall & Pocknall 1958
A. waitakiensis	(McIntyre) Mildenhall & Pocknall 1989
Clavatipollenites ascarinoides	McIntyre 1968
Liliacidites aviemorensis	McIntyre 1968
L. variegatus	Couper 1953
Sparganieaceaepollenites barungensis	Harris 1972
Tricolpate	
Perfotricolpites digitatus	Guzman 1967
Tricolpites confessus	Stover in Stover & Partridge 1973
T. discoides	New species (Chapter 6)
T. incisus	Stover in Stover & Partridge 1973
T. cf. *lilliei*	Couper 1953
T. occultum	New species (Chapter 6)
T. perlongicolpus	Pocknall & Mildenhall 1984
T. phillipsii	Stover in Stover & Partridge 1973
T. reticularis	New species (Chapter 6)
T. cf. *reticulatus*	(Cookson) Couper 1953
T. secarius	McIntyre 1965
T. simatus	Partridge in Stover & Partridge 1973
T. thomasii	Cookson & Pike 1954
T. cf. *thomasii*	Cookson & Pike 1954

Species	Author
Syncolpate-Syncolporate	
Cupanieidites major	Cookson & Pike 1954
C. orthoteichus	Cookson & Pike 1954
C. reticularis	Cookson & Pike 1954
Gothanipollis bassensis	Stover in Stover & Partridge 1973
Myrtaceidites corymbioides	New species (Chapter 6)
M. eucalyptoides	Cookson & Pike 1954
M. mesonesus/parvus	Cookson & Pike 1954
Tricolporate	
Ailanthipites mulleri	(Kemp) Milne 1988
A. paenestriatus	(Stover) Milne 1988
Bluffopollis scabratus	(Couper) Pocknall & Mildenhall 1984
Ilexpollenites anguloclavatus	McIntyre 1968
I. megagemmatus	McIntyre 1968
I. verrucatus	Pocknall & Mildenhall 1984
Rhoipites alveolatus	(Couper) Pocknall & Crosbie 1982
R. angurium	(Partridge) Pocknall & Mildenhall 1984
R. cf. *aralioides*	Pocknall & Mildenhall 1984
R. cissus	Macphail & Truswell 1993
R. fragilis	Mildenhall & Pocknall 1989
R. goulburnensis	Truswell & Owen 1988
R. hawkdunensis	Mildenhall & Pocknall 1989
R. ivanhoensis	(Martin) Wood 1986
R. microreticulatus	(Harris) Macphail & Truswell 1993
R. minutiformis	Truswell & Owen 1988
R. muehlenbeckiaformis	Macphail & Truswell 1993
R. oralongii	New species (Chapter 6)
R. orbiculatus	New species (Chapter 6)
R. rotundiformis	Truswell & Owen 1988
R. sphaerica	Cookson 1947
Schizocolpus marlinensis	Stover in Stover & Partridge 1973
T. adelaidensis	(Harris) Stover & Partridge 1982
T. cf. *cooksonii*	Martin 1973
T. leuros	Partridge in Stover & Partridge 1973
T. prolata	Cookson 1947
T. cf. *prolata*	Cookson 1947
T. scabratus	Harris 1965
Tricolporopollenites pelargonoides	Martin 1973
Polycolpate	
Nothofagidites brachyspinulosus	(Cookson) Harris 1965
N. emarcidus	(Cookson) Harris 1965
N. heterus	(Cookson) Stover & Evans 1973
N. incrassatus	Cookson 1959
N. falcatus	(Cookson) Hekel 1972
N. longispinosus	(Couper) Pocknall 1990
N. senectus	Dettmann & Playford 1968
N. spinosus	(Couper) Mildenhall & Pocknall 1989
N. vansteenisii	(Cookson) Stover & Evans 1973
Polycolporate	
Polycolporopollenites esobalteus	(McIntyre) Pocknall & Mildenhall 1984
Psilastephanocolporites micus	Partridge in Stover & Partridge 1973

Species	Author
Tetracolporate	
Sapotaceoidaepollenites latizonatus	(McIntyre) Mildenhall & Pocknall 1984
S. rotundus	Harris 1972
Tetracolporites palynius	Stover & Partridge 1982
Tetracolporopollenites sp.	Milne 1988
Diporate	
Banksieaeidites arcuatus	Stover in Stover & Partridge 1973
B. cooksonii	Mack & Milne ms
B. davidsonii	Mack & Milne ms
Tricolpoid	
Beaupreaidites diversiformis	Milne 1988
B. elegansiformis	Cookson 1950
B. verrucosus	Cookson 1950
Triporate	
Haloragacidites harrisii	(Couper) Harris 1971
Propylipollis biporus	Dudgeon 1983
P. robustus	Dudgeon 1983
P. sp. A	Milne 1988
P. sp. B	Milne 1988
Proteacidites adenanthoides	Cookson 1950
P. alveolatus	Stover in Stover & Partridge 1973
P. ambassadatus	New species (Chapter 6)
P. annularis	Cookson 1950
P. cf. *annularis*	Cookson 1950
P. beddoesii	Stover & Partridge 1973
P. bremerensis	Stover & Partridge1982
P. carobelindiae	Milne 1988
P. cirritulis	Milne 1988
P. colubrimodus	New species (Chapter 6)
P. confragosus	Harris 1972
P. crassus	Cookson 1950
P. crochetaria	New species (Chapter 6)
P. cumulus	Stover & Partridge 1982
P. cf. *grandis*	Cookson 1950
P. aff. *Grevillea*	Mack ms.
P. aff. *Isopogon*	Mack ms.
P. ivanhoensis	Martin 1973
P. kopiensis	(Harris) Dudgeon 1983
P. leightonii	Stover in Stover & Partridge 1973
P. cf. *leightonii*	Stover in Stover & Partridge 1973
P. microspinosus	New species (Chapter 6)
P. cf. *Propylipollis microverrucatus*	Truswell & Owen 1988
P. narnooensis	New species (Chapter 6)
P. nasus	Truswell & Owen 1988
P. nasus (small)	Truswell & Owen 1988
P. cf. *nexinus*	Pocknall & Mildenhall 1984
P. cf. *nitidus*	Dudgeon 1983
P. notredamus	Milne ms.
P. obscurus	Cookson 1950
P. cf. *ornatus*	Harris 1965
P. pachypolus	Cookson & Pike 1954
P. polygonalis	New species (Chapter 6)

Species	Author
P. protrudens	New species (Chapter 6)
P. pseudomoides	Stover in Stover & Partridge 1973
P. cf. *pseudomoides* sp. 1	Stover in Stover & Partridge 1973
P. cf. *pseudomoides* sp. 2	Stover in Stover & Partridge 1973
P. cf. *pseudomoides* sp. 3	Stover in Stover & Partridge 1973
P. punctiporus	Macphail & Truswell 1993
P. rectomarginis	Cookson 1950
P. rectus	Pocknall & Mildenhall 1984
P. reticulatus	Cookson 1950
P. cf. *reticulatus*	Cookson 1950
P. rickmanii	New species (Chapter 6)
P. rynthius	Stover & Partridge 1982
P. scitus	Stover & Partridge 1982
P. cf. *scitus*	Stover & Partridge 1982
P. cf. *simplex*	Dudgeon 1983
P. stipplatus	Stover & Partridge 1973
P. cf. *stipplatus*	Stover & Partridge 1973
P. subscabratus	Couper 1960
P. symphyonemoides	Cookson 1950
P. cf. *symphyonemoides*	Cookson 1950
P. tenuiexinus	Stover in Stover & Partridge 1973
P. tesselaria	New species (Chapter 6)
P. tuberculatus	Cookson 1950
P. tuberculiformis	Harris 1965
P. vaga	New species (Chapter 6)
Santalumidites cainozoicus	Cookson & Pike 1954
Triporopollenites ambiguus	Stover & Partridge 1982
T. cf. *ambiguus*	Stover & Partridge 1982
T. delicatus	Stover & Partridge 1982
T. gemmatus	Harris 1972
T. vargus	Stover & Partridge 1982
T. cf. *vargus*	Stover & Partridge 1982
Hexaporate	
Anacolosidites acutullus	Cookson & Pike 1954
A. luteoides	Cookson & Pike 1954
Stephanoporate	
Malvacipollis diversus	Harris 1965
M. spinyspora	(Martin) Mildenhall & Pocknall 1989
M. subtilis	Stover in Stover & Partridge 1973
Periporate	
Periporopollenites demarcatus	Stover in Stover & Partridge 1973
Pollen retained in tetrad	
Ericipites scabratus	Harris 1965

APPENDIX 10. Appendices for 'New *Banksieaeidites* species and pollen morphology in *Banksia* L. f.'

APPENDIX 10A. Lithological distribution of fossil *Banksieaeidites* pollen in core from Mulga Rock

Sample	Drill Hole	Depth	Lithology	*B. cooksonii*	*B. davidsonii*
6Q	NND-5028	45.8	Medium brown siltstone	4.0	3.0
1M	NNA-5510	43.0-44.0	Dark brown to black silt	4.5	+
2M	NNA-5510	44.0-45.0	Dark brown to black silt	4.0	0.5
5Q	NND-5028	45.0	Mid grey-brown siltstone	2.5	+
7R	NND-5030	41.6	Dark brown homogenous siltstone	2.5	+
5	CD-1-763	54.9-55.0	Dark brown-black lignitic clay	+	2.0
1A	CD-1-1	40.0-40.1	Lignitic clay	+	2.0
8R	NND-5030	42.2	Mid-dark brown homogenous siltstone	1.5	+
3S	NND-5030	46.2	Light-mid brown siltstone, minor sand	1.0	
2	CD-1-481	40.9-41.0	Mid-dark brown lignitic clay	+	0.5
1I	NNA-5605	41.0-42.0	Mid brown lignitic clay, minor coarse sand	0.5	
2I	NNA-5605	46.0-47.0	Dark brown-black lignite	0.5	
6I	NNA-5605	60.0-61.0	Dark brown-black lignite	0.5	
2K	NNA-5738	61.0-62.0	Brown-black lignite	0.5	+
5L	NNA-5507	54.0-55.0	Light brown siltstone, minor fine-med sand	0.5	+
7T	NND-5077	52.7	Mid brown siltstone, med-coarse sand		0.5
8A	CD-1-779	80.9-81.0	Carbonaceous, interlayered clay and fine-med sand	+	+
3D	CD-1-1485	38.9-39.0	Mid brown clay and lignitic clay	+	+
7D	CD-1-409	39.9-40.0	Brown lignitic clay	+	
3E	CD-1-779	44.9-45.0	Pale grey-brown clay, burrows	+	+
2F	CD-1-481	38.9-39.0	Black lignitic clay	+	
3F	CD-1-481	42.1-42.2	Mid-dark brown lignitic clay	+	+
1H	RC-0672	44.0-46.0	Dark brown lignite, minor fine-med sand	+	+
2H	RC-0672	50.0-52.0	Dark brown claystone	+	+
3H	RC-0672	52.0-54.0	Mid-brown lignite, fine sand dispersed	+	+
4H	RC-0672	56.0-58.0	Dark brown lignite, minor fine sand	+	+
5H	RC-0672	60.0-62.0	Dark brown lignite	+	

Sample	Drill Hole	Depth	Lithology	*B. cooksonii*	*B. davidsonii*
6H	RC-0672	64.0-66.0	Dark brown lignitic clay	+	+
3I	NNA-5605	50.0-51.0	Dark brown lignitic clay, minor sand	+	
5I	NNA-5605	56.0-57.0	Black lignitic clay	+	+
5K	NNA-5738	61.0-62.0	Dark brown sandy-clay, minor med-coarse quartz	+	+
6K	NNA-5738	64.0-65.0	Black carbonaceous silty fine-med sandstone	+	+
4L	NNA-5507	52.0-53.0	Black carbonaceous silty fine-med sandstone	+	
6L	NNA-5507	59.0-60.0	Brown lignite, sulphates, fine-med sand	+	
6P	NND-5028	39.6	Mid brown claystone	+	
3Q	NND-5028	43.6	Mid brown claystone	+	+
4S	NND-5030	51.3	Sandy med-dark brown siltstone	+	
1T	NND-5077	51.5	Mid-dark brown siltstone	+	
3T	NND-5077	51.9	Dark brown lignitic siltstone	+	+
5T	NND-5077	52.3	Dark brown siltstone		+
6T	NND-5077	52.5	Mid brown siltstone	+	+

APPENDIX 10B. Register of extant specimens of *Banksia*, from which illustrated pollen were collected

Herbarium sheet acquisition numbers are noted.

Banksia ashbyi Baker f.: 22°15'S, 113°51'E, WA, *A. S. George*, '27 May 1965', PERTH – 01722263.

Banksia ashbyi Baker f.: 29°52'S, 116°00'E, WA, *C. A. Gardner*, 'Feb. 1940', PERTH – 01722530.

Banksia ashbyi Baker f.: 27°08'S, 114°08'E, WA, *S. D. Hopper*, '17 Sept. 1979', PERTH – 04123476.

Banksia attenuata R. Br.: 35°01'S, 116°51'E, WA, *A. R. Annels*, '20 Nov. 1987', PERTH – 02665301.

Banksia attenuata R. Br.: 30°58'S, 115°42'E, WA, *R. Schuh & Brailovsky*, '9 Dec. 1997', PERTH – 05879302.

Banksia baxteri R. Br.: 34°26'S, 118°08'E, WA, *R. T. Wills*, '13 Dec. 1988', PERTH – 06370322.

Banksia baxteri R. Br.: 34°23'S, 118°14'E, WA, *C. A. Gardner*, '17 Jan. 1936', PERTH – 01706012.

Banksia baxteri R. Br.: 34°03'S, 119°40'E, WA, *C. A. Gardner*, '11 Feb. 1959', PERTH – 01730455.

Banksia burdettii Baker f.: 29°58'S, 116°05'E, WA, *Miss* Frape, 'May 1939', PERTH – 01090755.

Banksia burdettii Baker f.: 30°19'S, 115°54'E, WA, *C. A. Gardner*, 'March 1960', PERTH – 01090771.

Banksia burdettii Baker f.: 29°48'S, 115°50'E, WA, *B. Barnsley*, '25 Jan. 1979', PERTH – 01090356.

Banksia grandis Willd.: 31°57'S, 116°03'E, WA, *A. Morrison, '*29 Oct. 1904', PERTH – 01683578.

Banksia grandis Willd.: 31°29'S, 116°02'E, WA, *A. Strid*, '5 Dec. 1982', PERTH – 01683519.

Banksia grandis Willd.: 31°43'S, 116°30'E, WA, *G. J. Keighery & J. J. Alford*, '5 Dec. 1985', PERTH – 01730991.

Banksia menziesii R. Br.: 27°36'S, 114°20'E, WA, *P. G. Wilson*, '15 May 1968', PERTH – 01736299.

Banksia menziesii R. Br.: 30°12'S, 115°27'E, WA, *R. Davis*, '10 Feb. 1996', PERTH – 044401293.

Banksia menziesii R. Br.: 28°00’S, 114°12’E, WA, *S. Donaldson & G. Flowers,* ‘6 Sept. 1997’, PERTH – 05428238.

Banksia occidentalis R. Br.: 33°49’S, 122°05’E, WA, *B. Archer*, ‘3 May 1997’, PERTH – 05398878.

Banksia occidentalis R. Br.: 35°01’S, 117°53’E, WA, *C. Andrews*, ‘Jan. 1902’, PERTH – 01737694.

Banksia occidentalis R. Br.: 34°58’S, 117°43’E, WA, *Dr Diels & Pritzel*, ‘Jan. 1901’, PERTH – 01737732.

Banksia tricuspis Meisn.: 30°10’S, 115°11’E, WA, *A. G. Herbert,* ‘May 1931’, PERTH – 00999024.

Banksia tricuspis Meisn.: 30°10’S, 115°11’E, WA, *C. A. Gardner,* ‘July 1931’, PERTH – 00999539.

APPENDIX 10C. Register of illustrated *Banksia* and *Banksieaeidites* pollen

Species and Figure	Sample and Depth	Prep. No./Slide	Coordinate	Cat. No.
Banksia ashbyi				
3.A–C	PERTH01722263	B1C/1	U52/4	F52457
3.D	PERTH01722530	B2C/1	X56/4	F52458
3.E	PERTH01722530	B2C/S1-10	–	F52459
3.F–H	PERTH017225320	B2C/S1-10	–	F52460
B. attenuata				
3.I	PERTH05879302	B7B/1	U51/4	F52461
3.J–L	PERTH05879302	B7B/1	T45/2	F52462
3.M	PERTH05879302	B7B/1	T46/1	F52463
3.N	PERTH05879302	B7B/S1-9	–	F52464
3.O–Q	PERTH05879302	B7B/S1-9	–	F52465
B. baxteri				
4.A–C	PERTH06370322	B2B/1	X43/2	F52466
4.D	PERTH01706012	B3B/2	Y46/1	F52467
4.E–G	PERTH06370322	B2B/1	W39/0	F52468
4. H–J	PERTH06370322	B2B/S1-8	–	F52469
B. burdettii				
5.A,B	PERTH01090755	B5/1	Q54/0	F52470
5.C	PERTH01090755	B5/1	U58/4	F52471
5.D	PERTH01090356	B6/1	X44/2	F52472
5.E,F	PERTH01090771	B7/S1-6	–	F52473
5.G,H	PERTH01090771	B7/S1-4	–	F52474
B. grandis				
5.I–J	PERTH01730991	B1D/1	X45/3	F52475
5.K	PERTH01730991	B1D/1	X48/3	F52476
5.L	PERTH01683519	B2D/1	W49/4	F52477
5.M	PERTH01683578	B3D/S1-12	–	F52478
5.N–P	PERTH01683578	B3D/S1-12	–	F52479
B. menziesii				
6.A,B	PERTH04440293	B1/1	W46/1	F52480
6.C,D	PERTH05428238	B2/1	X61/4	F52481
6.E	PERTH04440293	B1/1	X52/0	F52482
6.F–H	PERTH05428238	B2/S1-4	–	F52483
B. occidentalis				
6.I	PERTH01737732	B5A/1	Y44/2	F52484
6.J	PERTH01737694	B6A/1	W36/2	F52485
6.K–M	PERTH01737694	B6A/1	W36/0	F52486
6.N	PERTH01737694	B6A/1	X55/3	F52487
6.O–R	PERTH01737732	B5A/S1-7	–	F52488
B. tricuspis				
7..A,B	PERTH00999024	B7C/1	X37/1	F52489
7.C,D	PERTH00999539	B8C/1	W45/0	F52490
7.E	PERTH00999024	B7C/1	X46/1	F52491
7.F–H	PERTH00999024	B7C/S1-11	–	F52492
7.I,J	PERTH00999024	B7C/S1-11	–	F52493

Banksieaeidites arcuatus				
1.A,B	NNA-5738/64–65 m	CM6K/2	T40/3	F52494
1.C,D	CD-1-779/44.9–50 m	CM3E/1	R55/0	F52495
1. E,F	CD-1-763/72.8–72.9 m	CM8/2	T57/3	F52496
B. cooksonii				
1.G–I	NNA-5507/52–53 m	CM4L/1	G53/4	F52497
1.J	NNA-5738/49–50 m	CM2K/2	P38/2	F52498
1.K,L	NNA-5738/64–65 m	CM6K/2	U47/1	F52499
1.M–O	NNA-5605/50–51 m	CM3I/2	E46/2	F52500
1.P–R	NND-5028/45.8 m	CM6Q/S1-1	–	F52501
1.S–V	NND-5028/45.8 m	CM6Q/S2-3	–	F52502
B. davidsonii				
A–C	CD-1-763/54.9–55 m	CM5/2	P50/2	F52503
D	CD-1-489/38.9–39 m	CM2F/1	J57/0	F52504
E–H	NNA-5510/43–44 m	CM1M/1	T56/4	F52505
I–L	CD-1-763/54.9–55 m	CM5/S2-1	–	F52506
M–O	CD-1-763/54.9–55 m	CM5/S2-1	–	F52507

APPENDIX 10D. Photographic plates of fossil *Banksieaeidites* and extant *Banksia* pollen

PLATE B1

Banksieaeidites arcuatus and *B. cooksonii* sp. nov., transmitted light microscopy (TLM) and scanning electron microscopy (SEM) images. Scale bars 10 µm for transmitted light microscope (TLM) and whole grain scanning electron (SEM) images, 1 µm for SEM surface detail, with dot preceding scale bar. **A–O.** TLM images. **A–F.** *B. arcuatus* Stover and Partridge 1973. **A–B.** Same grain, median and high focus respectively. **C–D.** Same grain. **C.** Median focus showing apertural collar. **D.** High focus on fine sculpture. **E–F.** Same grain, showing the aperture remains constricted in a well hydrated specimen. **E.** High focus on very thin collar. **F.** Median focus. **G–V.** *B. cooksonii*, sp. nov. **G–I.** Holotype. **G.** Low focus, on microrugulate sculpture. **H.** Median focus, showing wall structure and apertural notch. **I.** High focus on apertural collars. **J.** Mature grain, showing increase in aperture size, median focus on wall structure. **K–L.** Same grain, slightly immature specimen showing significantly thicker exine. **K.** Median focus on wall structure. **L.** High focus on microrugulate sculpture. **M–O.** Same grain, high, median and low focus. **P–V.** SEM images. **P–R.** Same grain. **P.** Whole grain. **Q, R.** Detail of tectum surface at different locations on grain. **S, T** (right grain)–**V.** Same grain. **S.** Part grain showing breakage of the tectum to reveal the columellae. **T.** Whole grains. **U, V.** Detail of tectum surface at differing magnification.

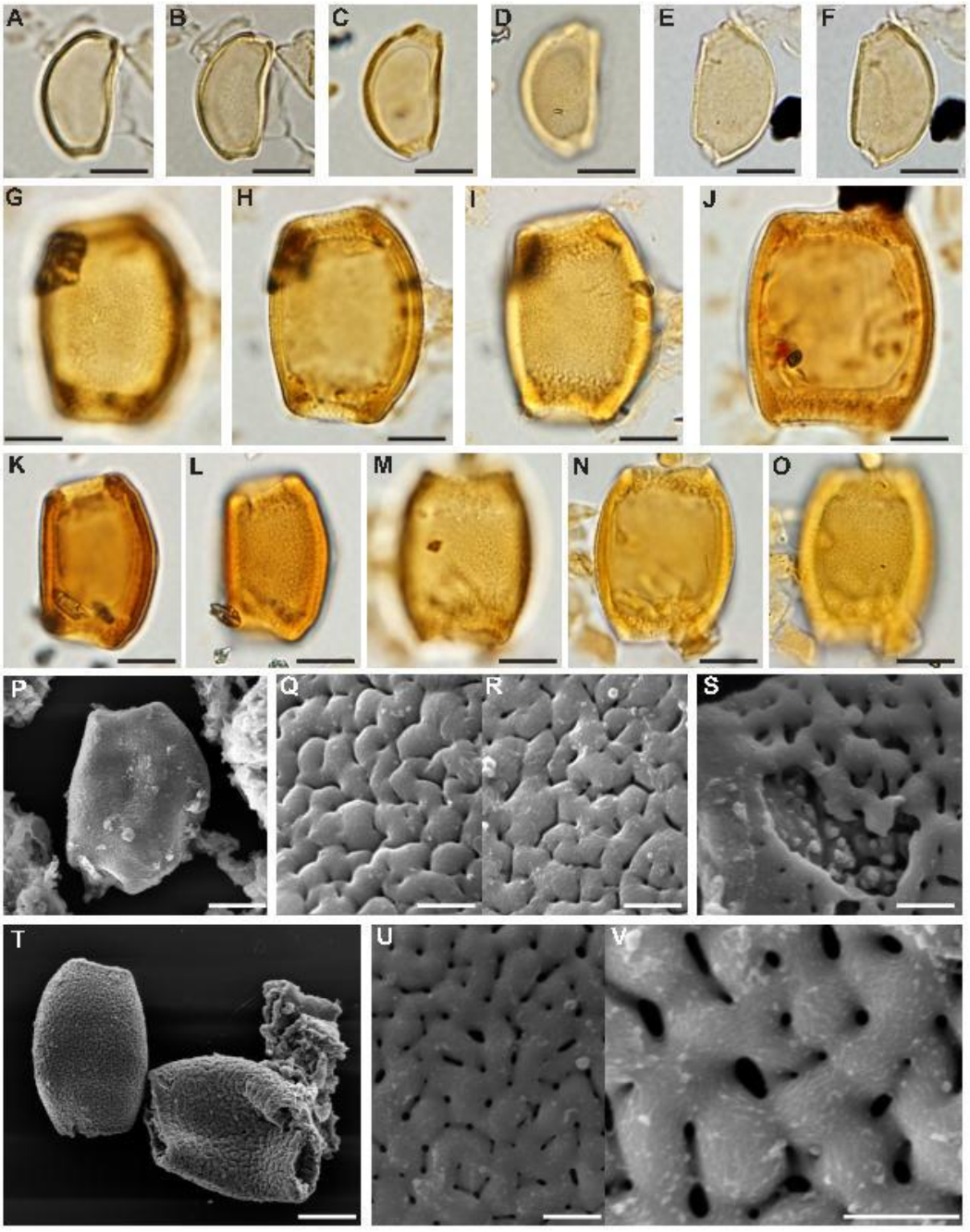

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V

PLATE B2

Banksieaeidites davidsonii sp. nov., TLM and SEM. Scale bars 10 μm for TLM and whole grain SEM images, 1 μm for SEM surface detail, with dot preceding scale bar. **A–H.** TLM images. **A–C.** Holotype. **A.** High focus showing apertural collars and psilate sculpture. **B.** Median focus showing exine stratification at the apertures and the nexine notch at the collars. C. Median to low focus showing mesoporial exine stratification. **D.** Low focus, grain oriented to show the planar side and slight curvature. **E–H.** Paratype. **E.** Low focus, showing microreticulate sculpture. **F.** High to median focus on apertural collars. **G.** Median focus showing wall stratification. **H.** Low focus showing microreticulate sculpture. **I–O.** SEM images. **I–L.** Same grain. **I.** Whole grain. **J.** Sculptural detail. **K.** Higher magnification of sculptural detail at the apertures. **L.** Higher magnification of polar sculptural detail. **M–O.** Same grain. **M.** Whole grain oriented to show planar side. **N, O.** Detail of tectum at differing magnifications.

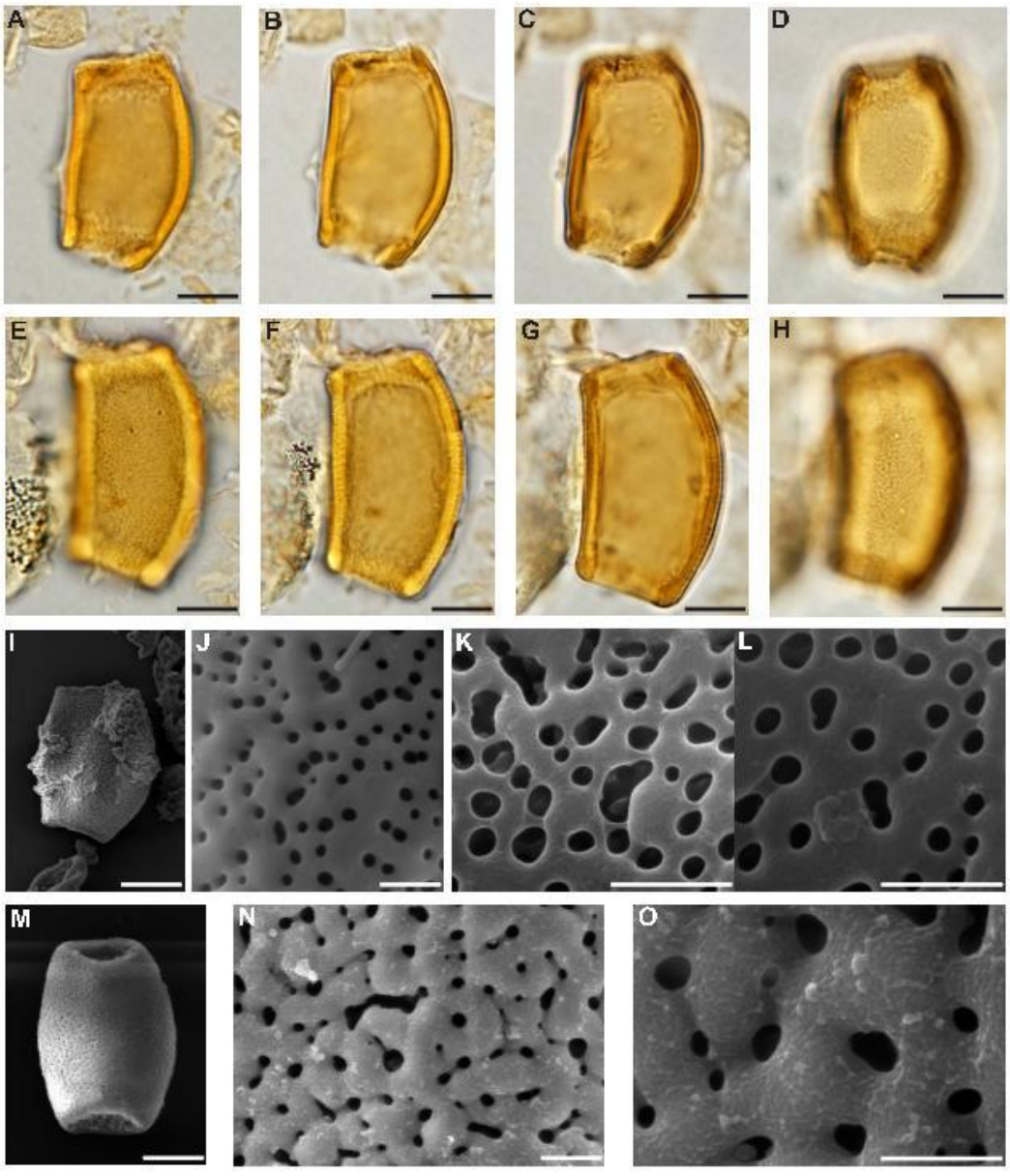

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O

PLATE B3

Banksia ashbyi and *B. attenuata* pollen TLM and SEM. Scale bars 10 µm for TLM and whole grain SEM images, 1 µm for SEM surface detail, with dot preceding scale bar. **A–H.** *B. ashbyi*. **A–C.** TLM of same grain. **A.** High focus showing slightly microrugulate sexine and apertural collars. **B.** Median focus on wall stratification and notches in the nexine at apertural collars. **C.** Low focus showing psilate sculpture. **D.** TLM of more mature grain, median focus showing widening of aperture and thinning of exine. **E–H.** SEM images. **E.** Whole grain. **F–H.** Same grain. **F.** Slightly immature whole grain. G. Sculptural detail showing perforation distribution and rugulae shape. **H.** Sculptural detail at higher magnification showing nanoscabrate tectum surface. **I–Q.** *B. attenuata.* **I–M.** TLM images. **I.** Median focus on more mature grain showing folding of grain in deflated specimens. **J–L.** Same grain. **J.** Low focus, showing psilate sexine. **K.** Median view of wall stratification and thinning of nexine at apertural collar. **L.** High focus of apertural collars and psilate sculpture. **M.** High focus on circular aperture and grain curvature. **N–Q.** SEM images. **N.** Very mature grain showing deflation and folding. **O–Q.** Same grain **O.** Whole grain, viewed along planar side. **P.** Sculptural detail showing distribution of perforations and rugulae morphology. **Q.** Higher magnification of sculptural detail showing finely nanoscabrate tectum.

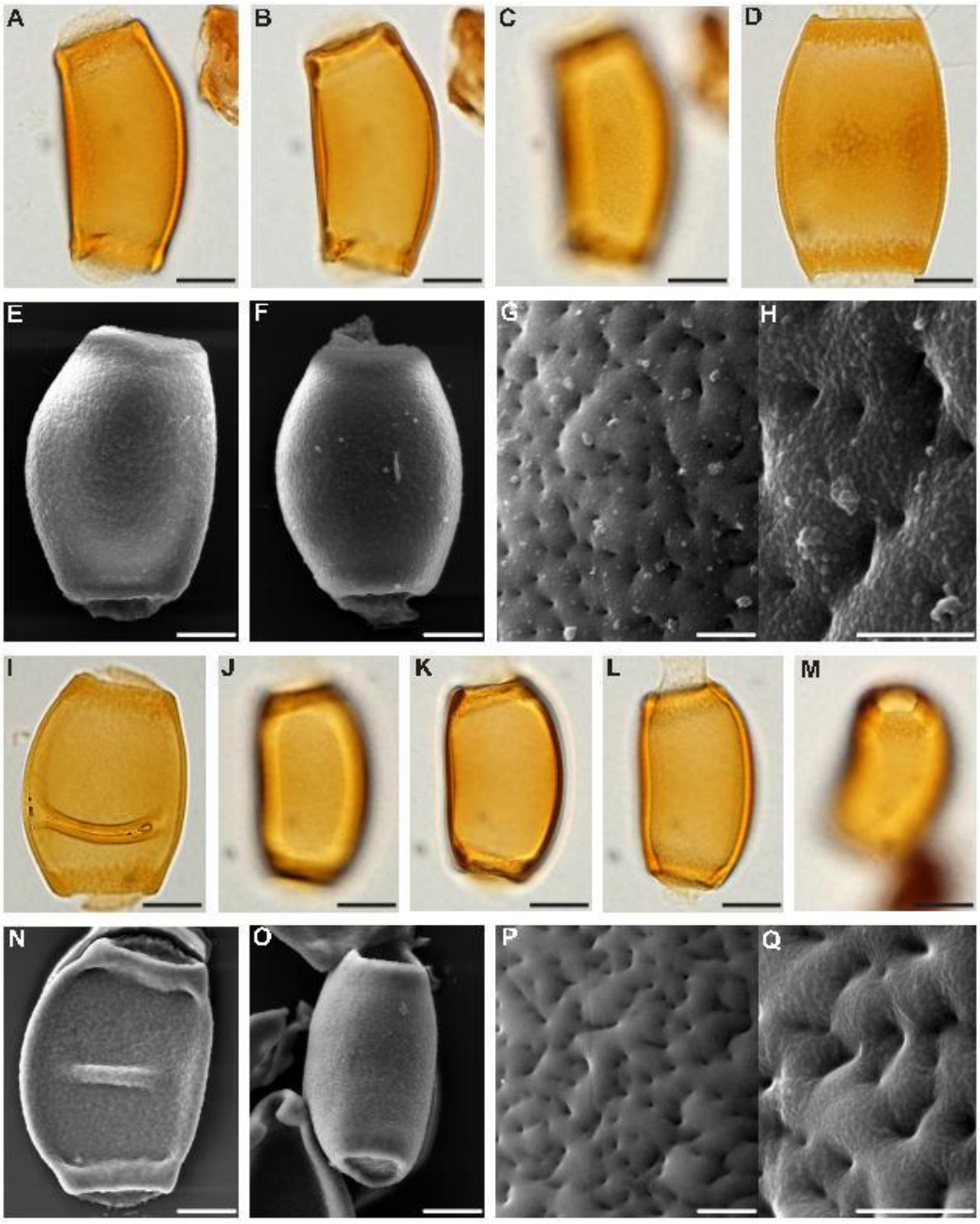

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q

PLATE B4

Banksia baxteri pollen, TLM and SEM. Scale bars 10 µm for TLM and whole grain SEM images, 1 µm for SEM surface detail, dot preceding scale bar. **A–G.** TLM images. **A–C.** Same grain. **A.** High focus showing rugulate sculpture. **B.** Median focus on wall structure and apertural notch. **C.** Low focus on surface showing rugulate sculpture. **D.** Median focus on mature grain showing expanded apertures, apertural collar and wall structure. **E–F.** Planoconvex specimen, same grain, low, median and high focus respectively. **H–J.** SEM images. **H.** Whole grain. **I.** Surface detail showing raised rugulae and distribution of perforations. **J.** Surface detail at higher magnification showing finely nanoscabrate surface of rugulae and perforations in valleys along rugulae margins.

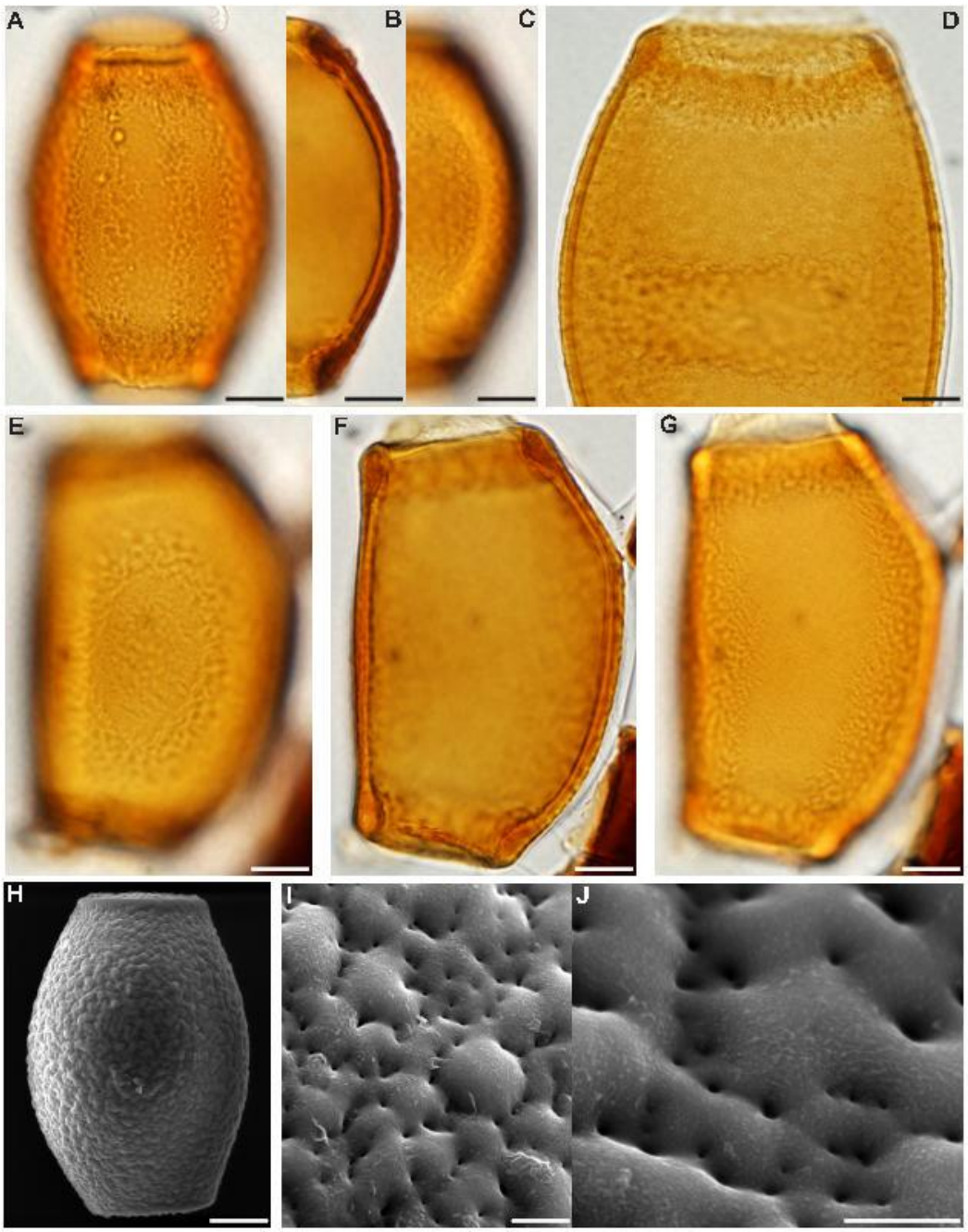

A
B
C
D
E
F
G
H
I
J

PLATE B5

Banksia burdettii and *B. grandis* pollen, TLM and SEM. Scale bars 10 µm for TLM and whole grain SEM images, 1 µm for SEM surface detail, with dot preceding scale bar. **A–H.** *B. burdettii.* **A–D.** Series of TLM images showing expansion of grain with maturity. **A, B.** Same grain. **A.** Median focus on exine structure. **B.** High focus on faintly microrugulate sculpture. **C.** Slightly more mature grain, median focus showing wall structure, apertural notches and apertural collar. **D.** Fully mature grain, with amb shape expanding to circular with truncated ends. **E–H.** SEM images. **E.** Whole grain. **F**. Surface detail on less mature specimen showing small circular perforations and low relief rugulae. **G, H.** Sculptural detail on mature specimen showing increase in perforation size and decrease in elevation of rugulae. **I–P.** *B. grandis.* **I–L.** TLM. **I, J.** Immature grain with truncated oval amb shape. **I.** Median focus showing wall structure and narrowing of nexine at the start of the apertural collar. **J.** High focus on distinct microrugulate sculpture and apertural collar. **K.** Slightly more mature grain, median focus showing thinning of exine as grain matures and widening of the amb. **L.** Mature grain, median focus, distinctly wider than immature specimen figured in I. **M–P.** SEM images. **M, N.** Whole grain images. **N–P.** Same grain. **O.** Sculptural detail. **P.** Sculptural detail at higher magnification showing nanorugulate structures perpendicular to rugulae and pairing of perforations due to sinking of the tectum.

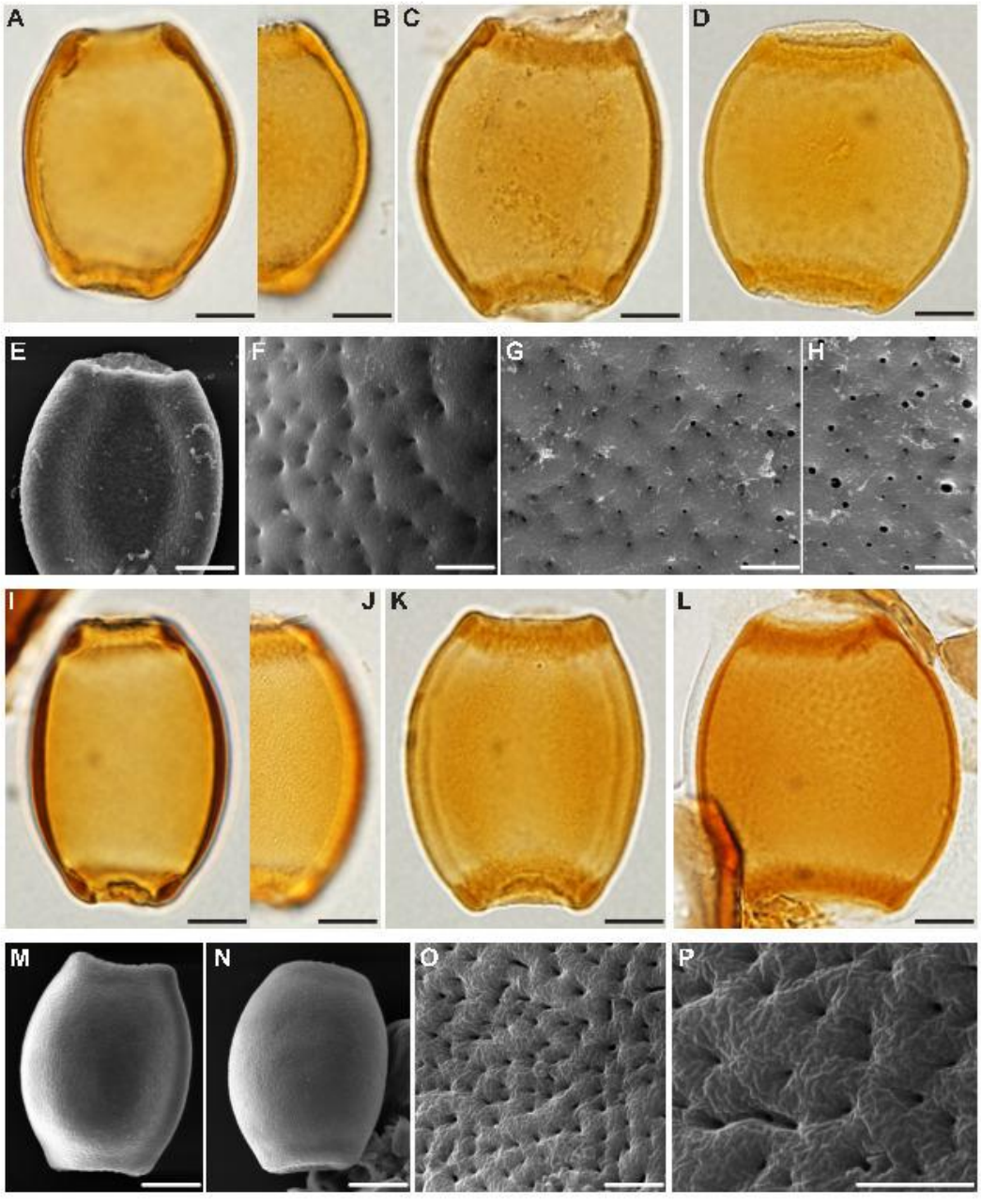

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P

PLATE B6

Banksia menziesii and *B. occidentalis* pollen, TLM and SEM. Scale bars 10 µm for TLM and whole grain SEM images, 1 µm for SEM surface detail, with dot preceding scale bar. **A–H.** *B. menziesii*. **A, B.** Same grain showing planoconvex amb shape. **A.** Median view showing exine stratification. **B.** High focus on faintly microrugulate sculpture and faint apertural collars. **C–D.** Same grain, immature, asymmetrically biconvex. **C.** Median focus on exine structure and apertural notch. **D.** High focus showing distinct microrugulate sculpture. **E.** Median focus of mature grain showing expansion of the apertures and distinct apertural collar. **F–H.** SEM images, same grain. **F.** Whole grain. **G.** Sculptural detail, showing rugulae and distribution of perforations. **H.** Higher magnification of sculptural detail, showing nanoscabrate tectum surface and connection of sunken tectum forming troughs. **I–R.** *B. occidentalis*. **I–N.** TLM images. **I.** Median focus on wall stratification of mature specimen, showing expansion of the apertures and width. **J.** Median focus on wall stratification and aperture, showing thinning of nexine prior to the aperture. **K–M.** Same grain, showing asymmetrically biconvex amb shape. **K.** Low focus showing faintly rugulate exine. **L.** Median view of exine stratification and thickening of nexine to the aperture. **M.** High focus on distinct microrugulate sculpture. **N.** High focus on sculpture of more immature grain, with narrower amb. **O–R.** SEM images, same grain. **O.** Whole grain. **P, R.** Sculptural detail showing perforate tectum. **R.** Sculptural detail at higher magnification showing nanoscabrate surface.

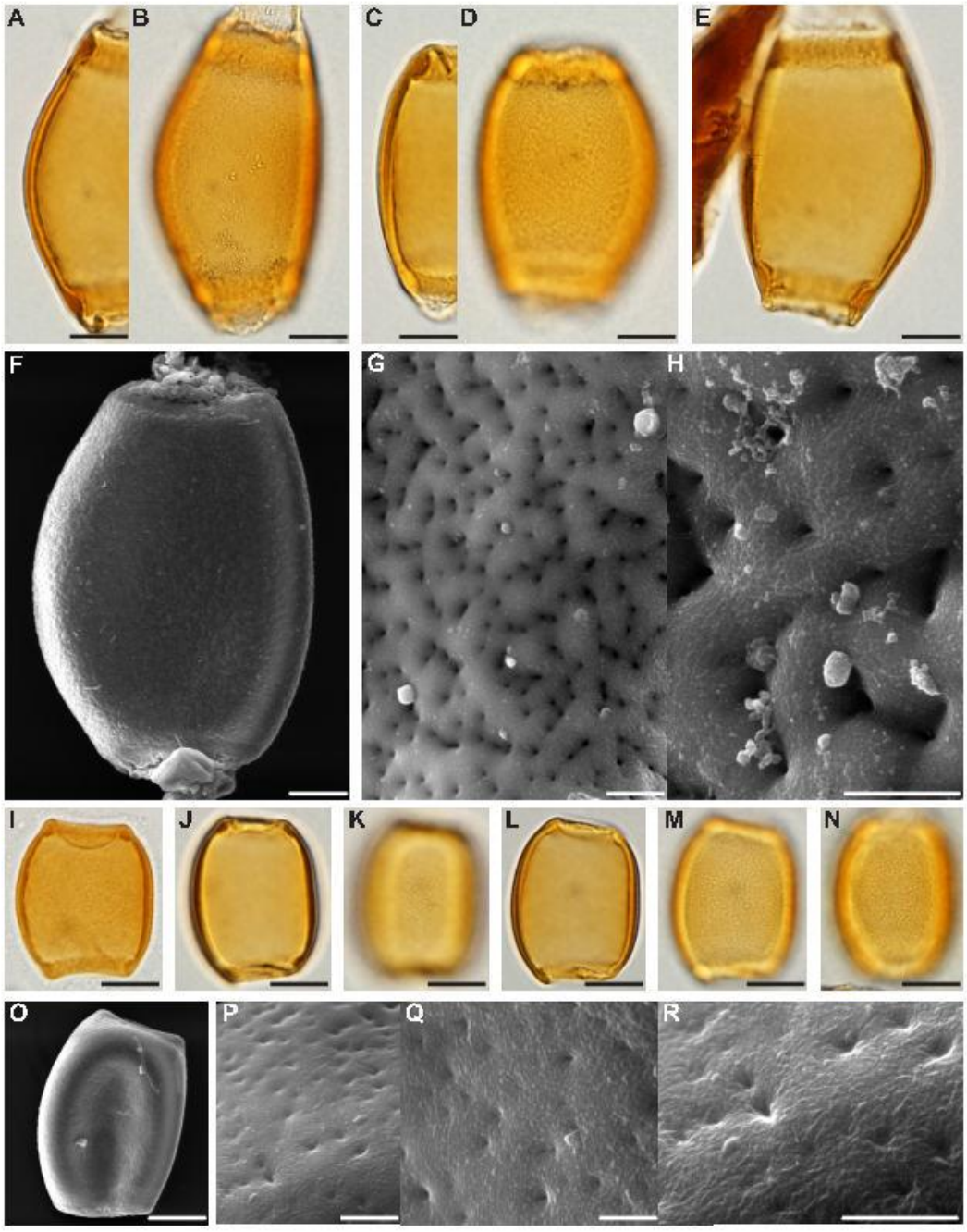
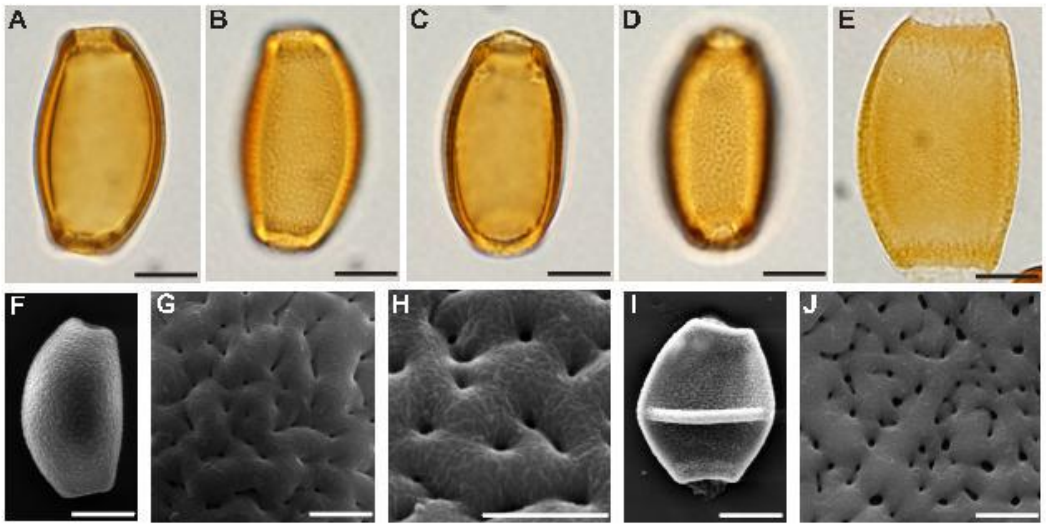

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R

PLATE B7

Banksia tricuspis pollen, TLM and SEM. Scale bars 10 µm for TLM and whole grain SEM images, 1 µm for SEM surface detail, with dot preceding scale bar. **A–E.** TLM images. **A–B.** Same grain, showing asymmetrically biconvex amb. **A.** Median focus on exine stratification and apertural notch. **B.** High focus on microrugulate sculpture. **C–D.** Symmetrically biconvex grain with slight curvature. **C.** Median focus on exine structure at top of grain, obscured at base due to grain curvature. **D.** Low focus on lower aperture and microrugulate sculpture. **E.** Mature grain, high focus showing expansion of apertures and microrugulate sculpture. **F–J.** SEM images. **F–H.** Same grain. **F.** Whole immature grain. **G.** Sculptural detail. **H.** Higher magnification of sculptural detail showing nanorugulate tectum surface. **I.** Whole grain image of mature grain, showing creasing as a result of deflation. **J.** Sculptural detail, showing decrease in relief and interwoven appearance of rugulae, and increase in size of perforations.


A
B
C
D
E
F
G
H
I
J

APPENDIX 11. Declaration of contribution to publication and copyright permission

DECLARATION OF CONTRIBUTION TO JOINT PUBLICATION

I, Dr Lynne Milne, declare that my contribution to the following publication:

Mack C. L. and Milne L.A. 2015 Eocene palynology of the Mulga Rocks deposits, southern Gunbarrel Basin, Western Australia. *Alcheringa* **39** (4), 444–458.

was 10% of the total, and that Charlotte Mack contributed 90%.

Signed: Lynne Milne

Date: 23/03/2016

PERMISSION TO USE COPYRIGHT MATERIAL AS SPECIFIED BELOW:

Mack C. L. and Milne L.A. 2015 Eocene palynology of the Mulga Rocks deposits, southern Gunbarrel Basin, Western Australia. *Alcheringa* **39** (4), 444–458.

I hereby give permission for Charlotte Mack to include the abovementioned material in her higher degree thesis for Curtin University, and to communicate this material via the espace@Curtin institutional repository. This permission is granted on a non-exclusive basis and for an indefinite period.

I confirm that I am the copyright owner of the specified material.

Signed: 

Name: Stephen McLoughlin

Position: Editor in Chief, *Alcheringa*
(Professor, Swedish Museum of Natural History)

Date: 23rd March, 2016

The only requirement we ask for reproduction of material from *Alcheringa* is that the full citation be given to the original article accompanying the reproduced image(s).

Please return signed form to charlotte.mack@postgrad.curtin.edu.au

APPENDIX 12. Fossil pollen species with botanical affinities and associated vegetation types.

References are given in Chapter 5 for affinities and the references herein are for the associated vegetation types only.

Species	Botanical affinity	Ecological group	Reference
Cryptogam spores			
Baculatisporites comaumensis	Osmundaceae	Wet forests and riparian; rainforest	Dodson and Macphail (2004)
Cibotiidites tuberculiformis	Dicksoniaceae	Wet forests and riparian; warm wet forest	Dodson and Macphail (2004)
Cyathidites australia/minor	Cyatheaceae	Wet forests and riparian; warm wet forest	Dodson and Macphail (2004)
Dictyophyllidites equiexinus	Dicksoniaceae	Wet forests and riparian; warm wet forest	Dodson and Macphail (2004)
Gleicheniidties circinidites	Gleichenaceae	Sedgeland, swamp and salt marsh	Dodson and Macphail (2004)
Laevigatosporites ovatus	Schizaeaceae	Sedgeland, swamp and salt marsh	Dodson and Macphail (2004)
Latrobosporites marginis	Lycopodiaceae, *Lycopodium laterale*	Sedgeland, swamp and salt marsh	Dodson and Macphail (2004)
L. ohaiensis	Lycopodiaceae	Widespread in Australia, in wetter areas	Beadle (1981)
Rugulatisporites micraulaxus	Thyrsopteridaceae	Wet forests and riparian	Dodson and Macphail (2004)
Gymnosperms			
Dacrycarpites australiensis	Podocarpaceae, *Dacrydium*	Wet forests and riparian: montane forest	Dodson and Macphail (2004)
Lygistepollenites florinii	Podocarpaceae, *Dacrydium bidwilli*	Wet forests and riparian: montane forest	Dodson and Macphail (2004)
Parvisaccites catastus	Podocarpaceae, *Lagarostobos franklinii*	Cool temperate rainforest and riparian	
Phyllocladidites mawsonii	Podcarpaceae, similar to *Podocarpus* and *Dacrydium*	Wet forests and riparian: montane forest	Dodson and Macphail (2004)
Podocarpidites ellipticus	Podocarpaceae, *Podocarpus*	Wet forests and riparian	Dodson and Macphail (2004)
P. puteus	Podocarpaceae, *Dacrycarpus dacrydioides*	Wet forests and riparian	Dodson and Macphail (2004)
Trichotomosulcites subgranulatus	Podocarpaceae, extinct *Microcachrys*	Heaths and shrubland	Beadle (1981)

Species	Botanical affinity	Ecological group	Reference
Angiosperms			
Monocolpate/Monosulcate			
Aglaoredia qualumis	Sparganiaceae	Sedgeland, swamp and salt marsh	Dodson and Macphail (2004)
Liliacidites aviemorensis	Liliales	Sedgeland, swamp and salt marsh	Dodson and Macphail (2004)
L. variegatus	Liliales	Sedgeland, swamp and salt marsh	Dodson and Macphail (2004)
Sparganiaceaepollenites barungensis	Sparganiaceae		
Tricolpate			
Perfotricolpites digitatus	Colvulaceae, *Polymeria-Merremia*	Dry forest types, woodland, savannah or heath	Dodson and Macphail (2004)
Syn(col)porate			
M. eucalyptoides	Myrtaceae, *Eucalyptus* (Bloodwood)	Dry forest types, woodland, savannah, heath	Dodson and Macphail (2004)
M. mesonesus/parvus	Myrtaceae	Broad range of environments	
Tricolporate			
Ilexpollenites anguloclavatus	Aquifoliaceae, *Ilex*	**Aus:** lowland forest, coastal and riparian, **worldwide:** many temperate and tropical areas	Morley and Toelken (1983), Florabase
I. megagemmatus	Aquifoliaceae, *Ilex*	**Aus:** lowland forest, coastal and riparian, **worldwide:** many temperate and tropical areas	Morley and Toelken (1983), Florabase
I. verrucatus	Aquifoliaceae, *Ilex*	**Aus:** lowland forest, coastal and riparian, **worldwide:** many temperate and tropical areas	Morley and Toelken (1983), Florabase
Rhoipites alveolatus	Acanthaceae, Euphorbiaceae, Caesalpiniaceae, Verbenaceae	Mangroves to moist tropics	Macphail (1999)
R. cissus	Sterculiaceae, *Cissus*	Wet forest and riparian: temperate rainforest	Dodson and Macphail (2004)
R. muehlenbeckiaformis	Polygonaceae, *Muehlenbeckia*	Dry forest types, woodland, savannah, heath	Dodson and Macphail (2004)

Species	Botanical affinity	Ecological group	Reference
Tricolporites adelaidensis	Meliaceae?, *Dysoxylum*	Understorey trees in rainforests	Morley and Toelken (1983)
T. valvatus	Ebenaceae, *Diospyros*	Wet forest and riparian	Dodson and Macphail (2004)
Tricolporopollenites geranioides	Geraniaceae, *Pelargonium*	Throughout temperate Australia	Morley and Toelken (1983)
Polycolpate			
Nothofagidites brachyspinulosus/incrassatus	Fagaceae, *Nothofagus* (*Fuscospora)*	Wet forest and riparian: temperate rainforest	Dodson and Macphail (2004)
N. emarcidus/heterus	Fagaceae, *Nothofagus* (*Brassospora*)	Wet forest and riparian: temperate rainforest	Dodson and Macphail (2004)
N. falcatus	Fagaceae, *Nothofagus* (*Brassospora*)	Wet forest and riparian: temperate rainforest	Dodson and Macphail (2004)
N. longispinosus	Fagaceae, *Nothofagus* (*Brassospora*)	Wet forest and riparian: temperate rainforest	Dodson and Macphail (2004)
N. senectus	Fagaceae, *Nothofagus* (*Fuscospora)*	Wet forest and riparian: temperate rainforest	Dodson and Macphail (2004)
N. spinosus	Fagaceae, *Nothofagus* (*Brassospora*)	Wet forest and riparian: temperate rainforest	Dodson and Macphail (2004)
N. vansteenisii	Fagaceae, *Nothofagus* (*Brassospora*)	Wet forest and riparian: temperate rainforest	Dodson and Macphail (2004)
Polycolporate			
Polycolporopollenites esobaltus	Polygalaceae	Dry forest types, woodland, savannah and heath	Dodson and Macphail (2004)
Tetracolporate			
Sapotaceoidaepollenites latizonatus	Sapotaceae	Wet forest and riparian	Dodson and Macphail (2004)
S. rotundus	Sapotaceae	Wet forest and riparian	Dodson and Macphail (2004)
Tetracolporites palynius	Meliaceae, *Dysoxylum*	Understorey trees in rainforests	Morley and Toelken (1983)

Species	Botanical affinity	Ecological group	Reference
Diporate			
Banksieaeidites arcuatus	Proteaceae, Musgraveinae	Wet forest and riparian: tropical rainforest	Dodson and Macphail (2004)
B. cooksonii	Proteaceae, *Banksia*	Dry forest types, woodland, savannah or heath	Dodson and Macphail (2004)
B. davidsonii	Proteaceae, *Banksia*	Dry forest types, woodland, savannah or heath	Dodson and Macphail (2004)
Tricolpoid			
Beaupreaidites diversiformis	Proteaceae, Conospermeae, *Beauprea*	Diverse bush and photophile forest	Pocknall and Crosbie (1988), Milne (1998)
B. elegansiformis	Proteaceae, Conospermeae, *Beauprea*	Diverse bush and photophile forest	Pocknall and Crosbie (1988), Milne (1998)
B. verrucosus	Proteaceae, Conospermeae, *Beauprea*	Diverse bush and photophile forest	Pocknall and Crosbie (1988), Milne (1998)
Triporate			
Bluffopollis scabratus	Strasburgeriaceae, *Strasburgeria*	Rainforest in New Caledonia	Jarzen and Pocknall (1993)
Haloragacidites harrisii	Casuarinaceae, *Gymnostoma/Casuarina*	Dry forest types, woodland, savannah, heath	Dodson and Macphail (2004)
Proteacidites adenanthoides	Proteaceae, *Andenanthos*	Sand plain to jarrah forest	Wrigley and Fagg (1989)
P. annularis	Proteaceae, *Xylomelum occidentale*	Dry forest types, woodland, savannah, heath	Dodson and Macphail (2004)
P. carobelindiae	Proteaceae, Conospermeae, possibly with *Petrophile*	Woodland, dry sclerophyll forest and heath	Milne (1998)
P. cirritulus	Proteaceae, Conospermeae, *Petrophile*	Woodland, dry sclerophyll forest and heath	Milne (1998)

Species	Botanical affinity	Ecological group	Reference
P. crassus	Proteaceae, possibly *Adenanthos*	Sand plain to jarrah forest	Wrigley and Fagg (1989)
P. aff. *Grevillea*	Proteaceae, possibly *Grevillea*	**WA:** Mallee to sand plain, **east:** heath, open forest, few rainforest	Wrigley and Fagg (1989)
P. aff. *Isopogon*	Proteaceae, *Isopogon*	Dry forest types, woodland, savannah, heath	Dodson and Macphail (2004)
P. ivanhoensis	Proteaceae, *Orites*	Alpine shrubs or rainforest trees, one TAS species in temperate rainforest	Wrigley and Fagg (1989)
P. cf. *nexinus*	Proteaceae, *Symphionema*	Wet, peaty heaths, occasionally drier heaths	Wrigley and Fagg (1989)
P. obscurus	Proteaceae, *Agastachys*	Dense forest and edge of grass plains	Wrigley and Fagg (1989)
P. pseudomoides	Proteaceae, *Lomatia*	Range of ecological niches; rainforest, forests and open woodland, exposed heaths, dry and wet sclerophyll	Wrigley and Fagg (1989)
P. punctiporus	Proteaceae, *Stirlingia*	Dry forest types, woodland, savannah, heath	Dodson and Macphail (2004)
P. subscabratus	Proteaceae, *Petrophile*	Woodland, dry sclerophyll forest and heath	Dodson and Macphail (2004)
P. symphyonemoides	Proteaceae, *Symphionema*	Wet, peaty heaths, occasionally drier heaths	Wrigley and Fagg (1989)
Santalumidites cainozoicus	Santalaceae, *Santalum*	Widespread; tropics and temperate regions, including dry and arid areas	Morley and Toelken (1983)
Triporopollenites ambiguus	Proteaceae, possibly *Telopea*	Dry and wet sclerophyll forest, alpine shrubland, temperate rainforest to rainforest	Wrigley and Fagg (1989)
T. delicatus	Proteacae, possibly *Lomatia*	Range of ecological niches; rainforest, forests and open woodland, exposed heaths, dry and wet sclerophyll	Wrigley and Fagg (1989)
Stephanoporate			
Malvacipollis diversus	Euphorbiaceae, *Austrobuxus*		
M. spinyspora	Euphorbiaceae, *Micrantheum*		

Species	Botanical affinity	Ecological group	Reference
M. subtilis	Euphorbiaceae, *Austrobuxus*		
Periporate			
Periporopollenites demarcatus	Trimeniaceae	Tropical and subtropical rainforest	Morley and Toelken (1983)
Pollen retained in tetrad			
Ericipites scabratus	Ericales; *Epacridaceae*, *Ericaceae*	Dry forest types, woodland, savannah, heath	Dodson and Macphail (2004)